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Plant Response to 14 Engineered Log Jams on the North Fork Toutle River, WA Sediment Plain

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Plant Response to 14 Engineered Log Jams on the North Fork Toutle River, WA Sediment Plain

by

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A project report submitted in partial fulfilment of the requirements for the degree of

Master of Environmental Management

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Abstract

I sought to evaluate the vegetative response to the installation of the 14 engineered log jams (ELJs) on the North Fork Toutle River (NFTR) Sediment Plain. The NFTR sediment plain is constantly being reworked due to channel bank erosion caused by a combination of processes including flow erosion and gravitational mass failure. Vegetation has the ability to protect the bank from erosion as well as providing other stabilizing effects. The ELJ structures were designed in part to protect localized areas of the sediment plain and allow vegetated islands to develop. The purpose of these vegetated islands is to trap sand sized sediment that would otherwise pass over the spillway at a Sediment Retention Structure (SRS), and serve as a seed bank and possible point for continued vegetation establishment across the rest of the sediment plain. I utilized vegetation transects to collect raw vegetation data and then analysed the data to characterize the plant communities directly downstream from each ELJ. It was found that the ELJs are having moderate success creating protected vegetated islands. The NFTR sediment plain is dominated by pioneer species with *Alnus rubra* as the most abundant species. A total of 42 species were identified to the species level (20 native species, 22 non-native species). Plant assemblages remain broadly similar across the sediment plain, although wetland indicators species are absent in the northern third of the Study Area. The Study Area was found to have 29.01% vegetation cover, compared to 8.8% vegetation cover in the Control Area. The Study Area was also found to have higher plant species richness and diversity than the Control Area. The vegetation behind the ELJs is able to trap sediment but releases that sediment if the vegetation interacts with the larger branches of the NFTR. It is recommended that the ELJs receive regular maintenance including re-racking of the structures.

Acknowledgements

Special thanks to Dr. Colin Thorne for the opportunity to work on such a diverse project. Colin was integral to my portion of the study and provided expertise, guidance, and support. The project also would not have been possible without the field assistance and GIS expertise of Joshua Townsend. Thanks to Dr. Alan Yeakley, Dr. Yangdong Pan, and Dr. Joseph Maser for providing guidance in establishing research methods. Thanks do Christopher Mikes for lending his expertise in ArcGIS.

I would also like to thank the USACE, Portland District for making this project possible and specifically Tina Teed for providing project support, and to Paul Sclafani for serving on my MEM Committee.

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1. Introduction and Scope

The research presented in this paper made up the biotic study portion of a larger final report that was completed for the Portland District, US Army Corps of Engineers:

THORNE, C., TOWNSEND, J. AND ASHLEY, T. 2014. 'Geomorphic and Ecological Assessment and Evaluation of Grade Building Structures on the SRS Sediment Plain, North Fork Toutle River' Final Report to the Portland District, US Army Corps of Engineers, under contract number W9127N-13-P-0072, January 2014, 166 pages.

The aim of the project was to assess, evaluate and visualise the morphological, sediment and ecological performance of the fourteen "engineered log jams" (ELJs) constructed for a 2010 pilot project. The aim of the biotic study was to evaluate the vegetative response to the installation of the ELJs on the Sediment Plain and characterize the plant species composition directly downstream from each structure.

1.1 Historical Context

On May 18th, 1980 the Mount St. Helens stratovolcano erupted with an initial lateral blast that swept across 230 square miles with an arc radius 180 degrees north of the volcano. Subsequent debris flows, pyroclastic flows, tephra fall, and lahars transformed hundreds of square miles of the surrounding landscape (Major, 2009). The majority of the 3.4 billion cubic yard (bcy) debris avalanche was deposited in the North Fork Toutle River (NFTR), burying the upper 17 miles of the valley at an average depth of 130 ft. and a maximum depth of 460 ft. Just hours after the debris avalanche a lahar deposited an additional 183 million cubic yards of sand, gravel, and debris with an average thickness of 15 ft. in the lower NFTR Valley (Pearson, 1985).

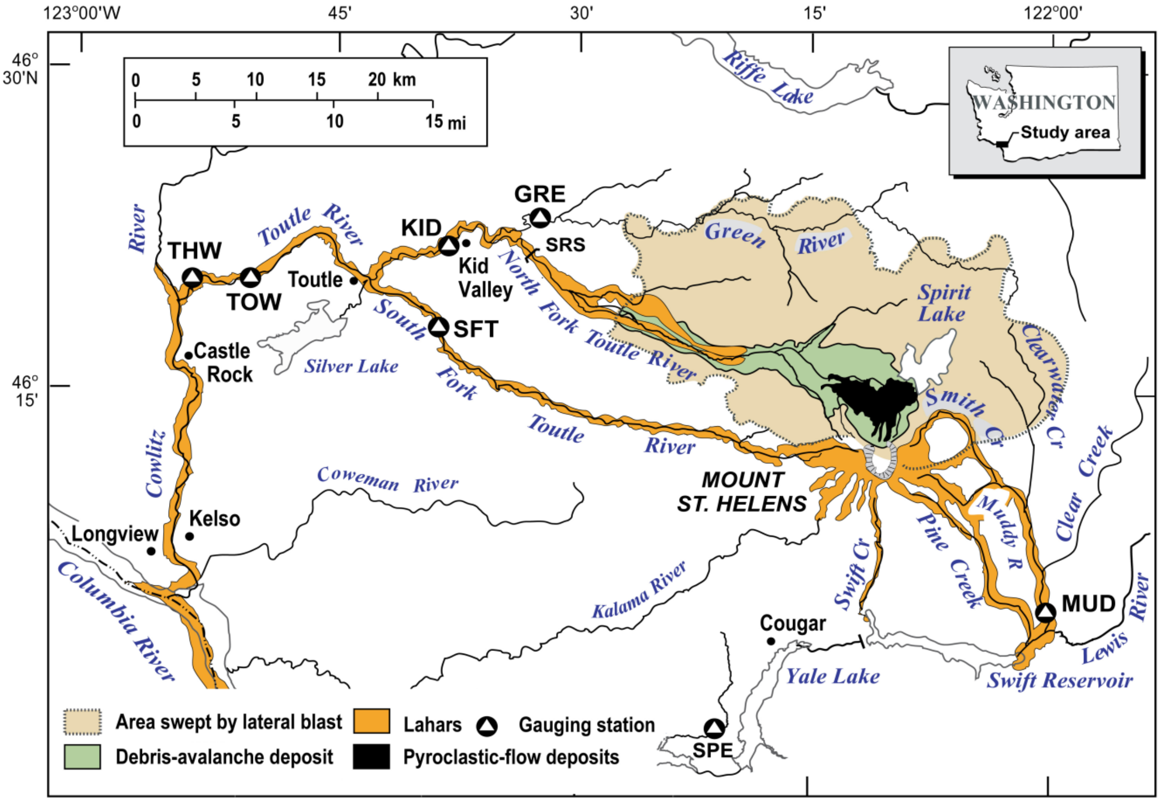


Figure 1.1 Distribution of major volcanogenic deposits associated with the 18 May, 1980 eruption. USGS gauging stations indicated for reference (Modified by Dr. Colin Thorne from Major et al., 2009).

These events radically altered the NFTR including the terrain and hydrology of the headwater catchment system, stripping soil and vegetation. The land surface and channel bed were inundated with sediment at depths up to several hundred feet, creating a massive new source of sediment. The post-eruption headwaters of the North Fork Toutle constitute the Spirit Lake Outlet Tunnel (USGS, 2013) as well as highly-eroded slopes comprised of extremely thick volcanogenic deposits. These deposits are typically made up of gravelly and silty tephra originating from the 1980 eruption and subsequent debris flow. Further downstream, substantial debris avalanche sediment persists, which mixes with thick (mean depth of 15 ft.) well-sorted sand and gravel deposits originating from significant lahar and mudflow events (Pearson, 1985, Major et al. 2000). The channel form is of relatively young age and is highly braided on the sediment plain. The river mainstem and braided streams shift rapidly and dynamically year-to-year. The NFTR was transformed from a pool-riffle stream with a meandering platform to a mixed sand/gravel bed with a braided stream system. The wandering, braided stream is continuously reworking the wide braid plain which is bereft of vegetation. More than a decade after the eruption, sediment transported by and deposited along the NFTR was approximately 500 times greater than pre-disturbance levels with the majority of material coming from the debris avalanche deposit. Sediment transport levels have subsided, but are still well above pre-eruption conditions as the NFTR continues to experience stream bank retreat, sheet erosion, and mass failure of un-vegetated slopes (Major, 2000).

The NFTR drains a watershed of approximately 152 mi^2 to the north-west of Mount St Helens, which is part of the volcanically active orogenic belt known as the High Cascades Range (Schwager et al., 2010). The river originates on the northern flank of Mount St. Helens and flows approximately 34 mi west to its confluence with the Green River. 15.5 mi downstream, close to the settlement of Toutle, where the North and South Forks confluence to form the Toutle River. The Toutle River in turn confluences with the Cowlitz River just north of Castle Rock, which then flows south for approximately 20 mi to its junction with the Columbia River near Longview (Pearson, 1985) (Figure 1.2).

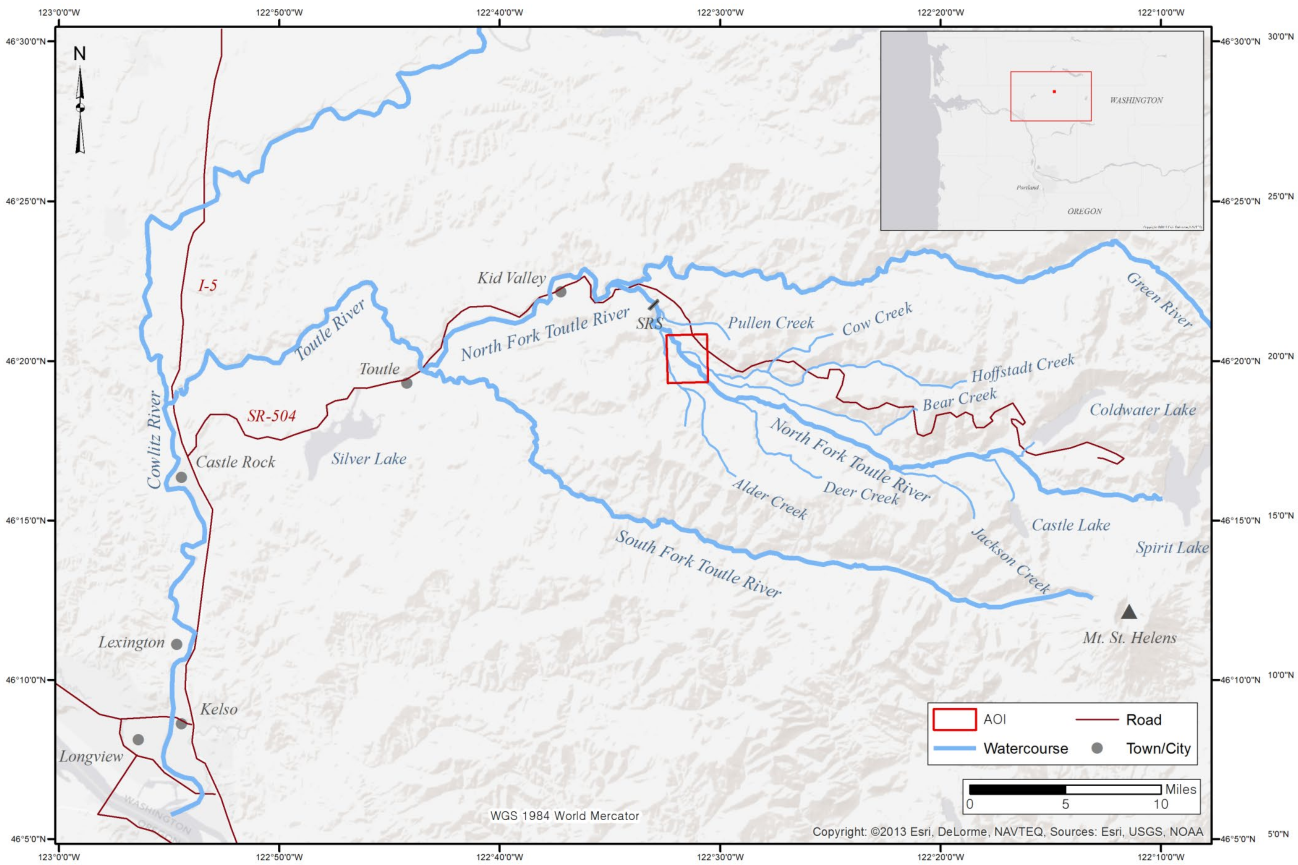


Figure 1.2 Location of the project's 'Area of Interest' within the Toutle drainage network in Washington State. Map created by Josh Townsend.

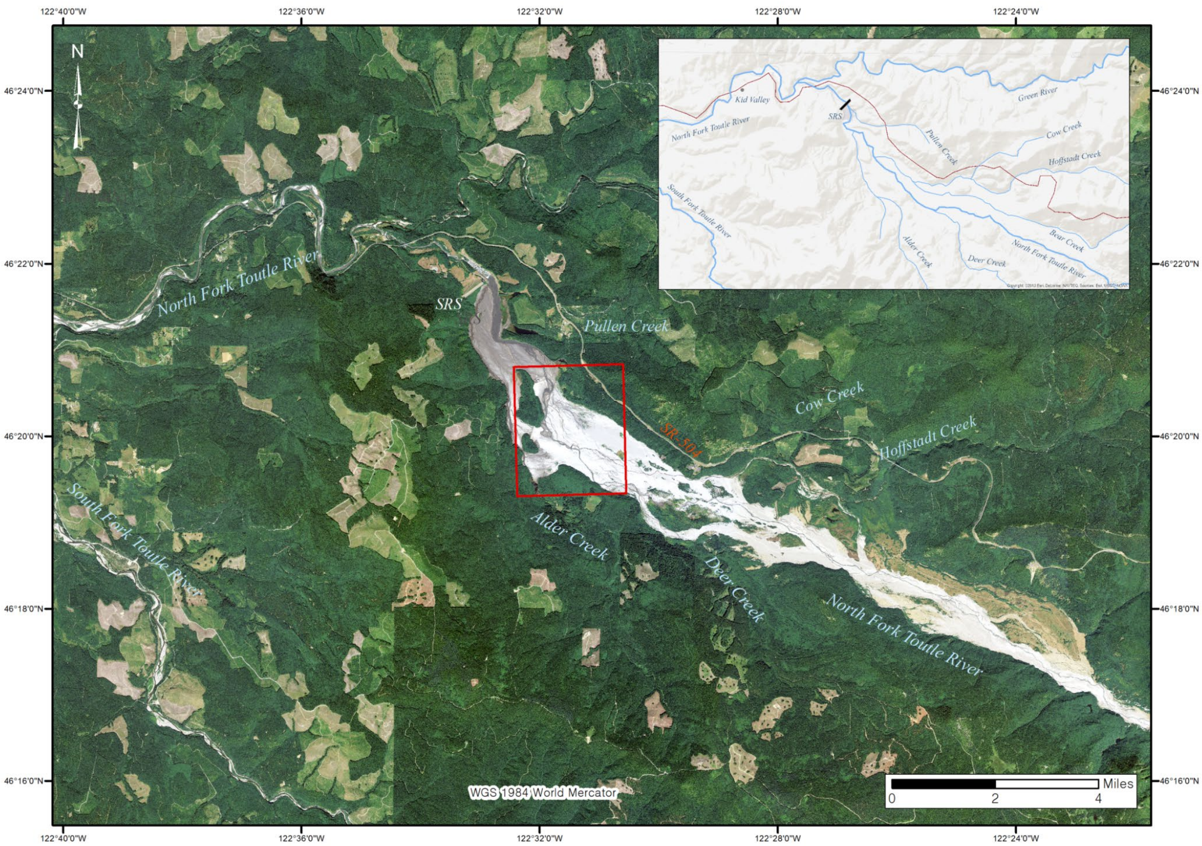


Figure 1.3 Vicinity map of the ‘Area of Interest’ of the NFTR. Aerial Imagery: 17th August 2011 (©USDA). Inset topographic map created by Josh Townsend.

Elevated sediment inputs from the NFTR significantly increase flood risks for downstream populations as well as communities along the Cowlitz River. The USACE implemented short term measures to reduce sediment quantities transported from the NFTR in order to reduce flooding risks and re-open navigation channels, but a longer term solution was needed (USACE, 1983; Denlinger, 2012). In 1989 the USACE completed an earth dam 1800 ft. in length and 125 ft. high across the NFTR known as the NFTR Sediment Retention Structure (SRS). “The SRS was designed to trap sediment by impounding water to reduce the energy slope and slow velocities in the NFTR so that its capacity to transport sediment was reduced and sediment was deposited upstream of the dam” (USACE, Portland District, 2009). The installation of the SRS caused sediment to build up behind the dam turning that portion of the NFTR into a sediment plain. The sediment plain is approximately 7 mi long and 60 ft. deep. For more than a decade the SRS had a trap efficiency of approximately 92% before the level of deposited sediment reached the SRS spillway invert reducing its trapping efficiency to approximately 31% (USACE, Portland District, 2009).

In 2009 the USACE organized an expert workshop in order to identify possible sediment management options for reducing the amount of sediment, particularly sand, from entering the Cowlitz River via the NFTR. Through this workshop the USACE commissioned the “Mount Saint Helens Grade Building Structures Pilot Project”. The project consisted of island/grade building structures in the form of fourteen “engineered log jams” (ELJ’s), a cross-valley structure, and a diversion berm. The ELJ structures were built approximately two miles upstream from the SRS during the summer of 2010 (USACE, 2010a).

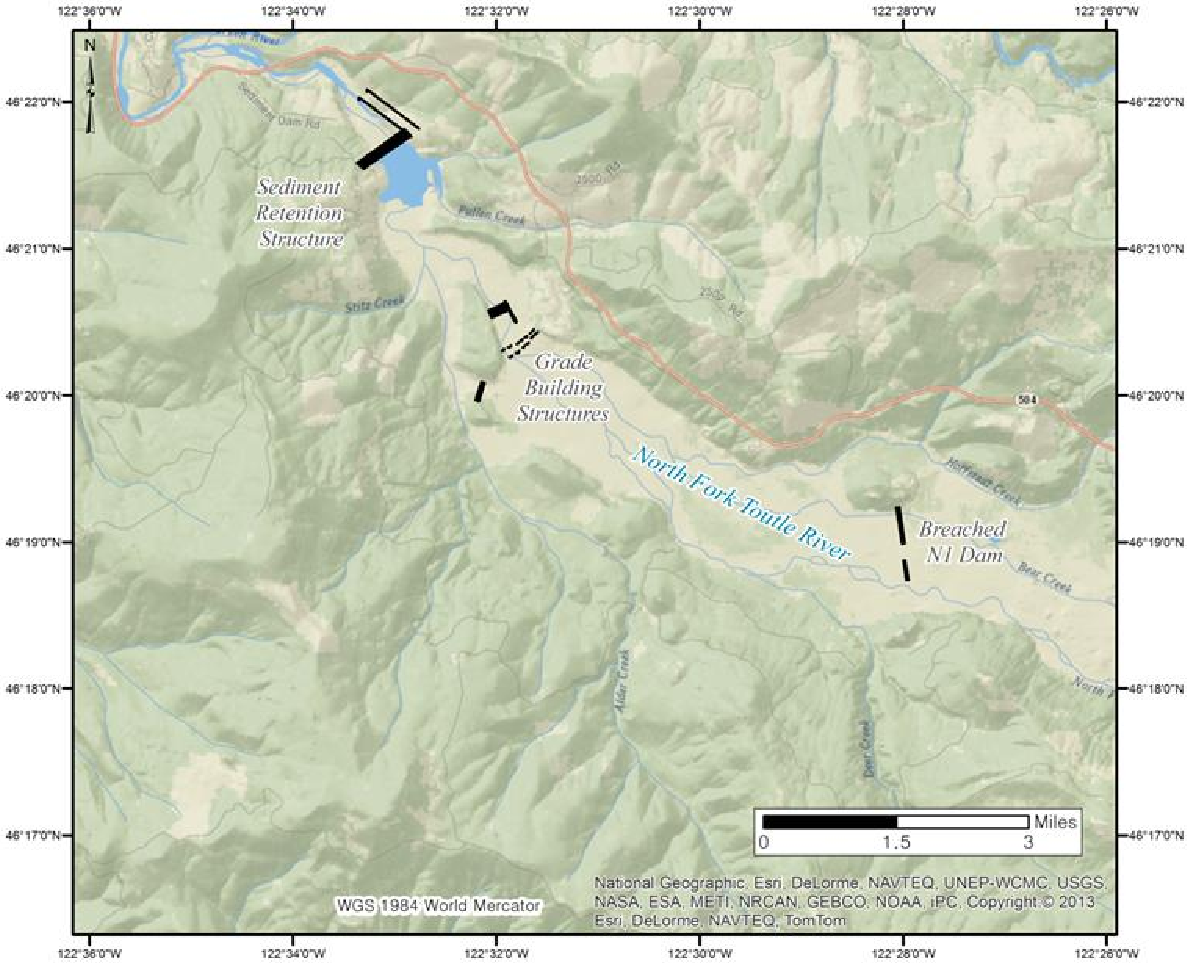


Figure 1.4 Location map for the N-1 dam, SRS, and Grade Building Structures (including the Cross-valley Structure, False Valley Wall and Cut-off Dam). Map drawn by Josh Townsend.

The ELJ structures were designed in part to protect localized areas of the sediment plain and allow vegetated islands to develop. The purpose of these vegetated islands is to trap sand sized sediment that would otherwise pass over the spillway at the SRS, stabilize and retain that sand, reduce rates of lateral channel migration and reworking of the sediment plain that re-erodes deposited sand, and serve as a seed bank and the starting point for continued vegetation establishment across the rest of the sediment plain.

The skeletal structure of each ELJ comprises stripped logs (some complete with root wads) securely bolted to two lines of 30 in. diameter wooden piles driven deeply into the sediment plain at approximately 10 ft. intervals. The rectangular central body of thirteen of the structures is flanked on both sides by “wings” consisting of piles driven along two lines angled downstream to deflect oncoming flow around the main body of each ELJ. The one structure that differs is ‘Straw’, which required no wing on its left margin, because this is immediately adjacent to a naturally stable, rocky outcrop in a large island within the sediment plain (Figure 1.5(a)). The front of each structure is covered (‘racked’) with woody debris of mixed sizes termed ‘racking’ (Figure 1.5(b)). There are three sizes of structure: Type A (span width wing tip to wing tip = 78 ft.; Type B (span = 112 ft.) and Type C (span = 168 ft.).

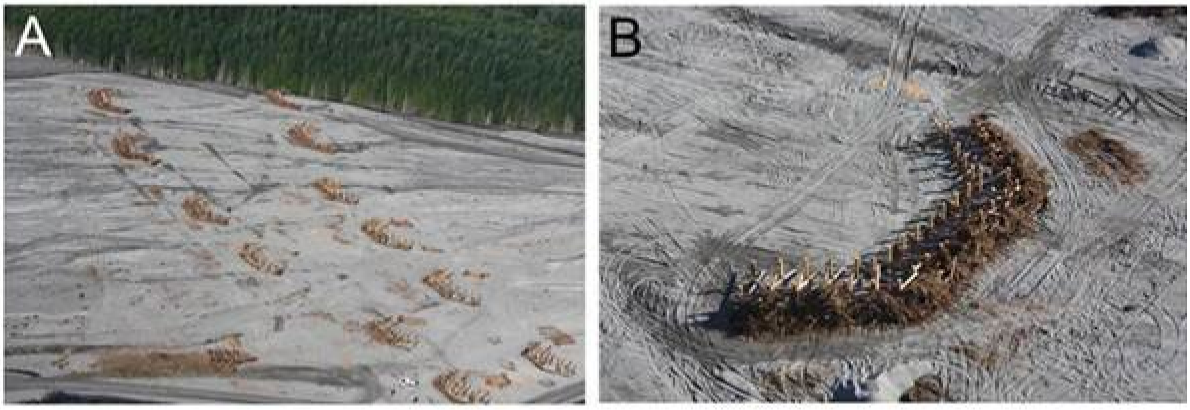


Figure 1.5 (a) ELJs under construction on the sediment plain in August 2010. For scale, the width of sediment plain is 0.34 miles. Note: The single winged structure “A-Straw” (circled in red) differs from the other 13 in that it has no left wing. Photo. supplied by LKE Corp. (b) Type-C structure “H-John” complete in August 2010. Width of structure is 168ft from wing tip to wing tip. Note large volume and brown colour of fresh racking material on front of structure. Photo. supplied by LKE Corp.

The ELJs span the sediment plain in two rows, each including seven structures and extending from Al Raught Park Island to the northern edge of the sediment plain (Figs. 1.5 and 1.6).

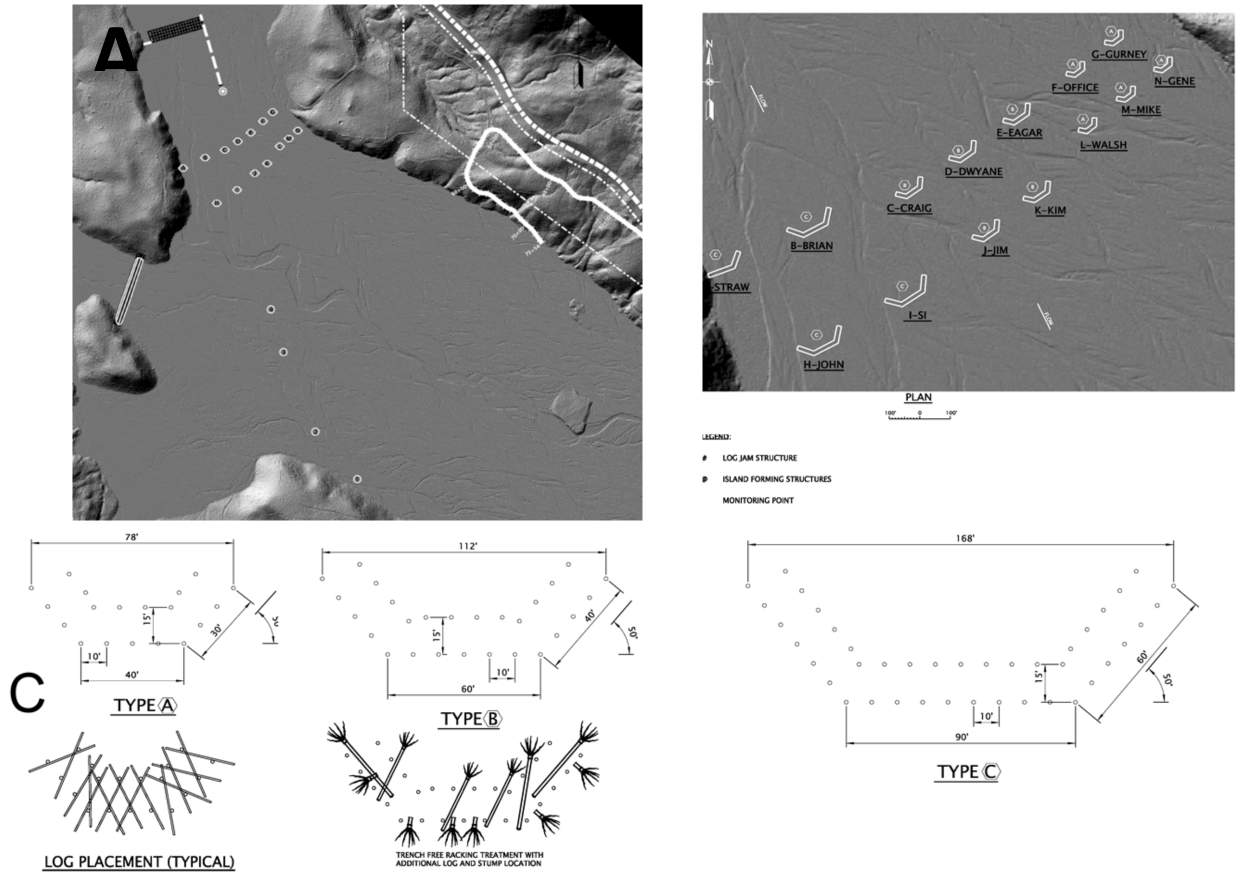


Figure 1.6 ELJ As-Builts

The sediment plain is constantly being reworked due to channel bank erosion caused by a combination of processes including flow erosion and gravitational mass failure. Vegetation has the ability to protect the bank from erosion as well as providing other stabilizing effects including soil reinforcement via root system development and the reduction of soil moisture content via canopy interception and evapotranspiration (Thorne, 1990). In-stream and floodplain vegetation can also decrease flow velocities and increase the amount of horizontal surface per unit volume to promote increased sedimentation (Elliot, 2000).

The Portland District USACE is interested in assessing and evaluating the performance of the ELJs in both these respects, to better understand how vegetation on the sediment plain might be promoted and managed.

The USACE is also interested in the use of vegetation (either planted or naturally recruited) to help promote improved habitat development. It is currently unclear if planting is a viable and/or cost-effective option, but a study of the vegetation in and around the ELJs should help inform that question as well shed light on issues pertaining to environmental management of the sediment plain. In this context, vegetation that has established on the islands protected by the ELJs present a possible model of the plant species assemblages that are best adapted to colonising and occupying the sediment plain more generally.

In light of these considerations, the biotic study performed as part of post-project appraisal of the ELJs sought to survey and characterize the plant communities that have established immediately downstream from the structures in the ELJ Study Site and compare those plant communities to ones located within the Control Study Site upstream. To this end, the Biotic Study employed transect plant surveying methods and statistical analyses.

2. Aim and Objectives

The aim of the biotic study was to evaluate the vegetative response to the installation of the fourteen ELJs on the Sediment Plain and characterize the plant species composition directly downstream from each structure. Comparing how the communities differ between structures should provide insight regarding how vegetation communities respond to different physical conditions and environments on the sediment plain. Physical factors of interest include: proximity to an active sub-channel, distance from valley side, and sediment aggradation. Plant species interactions are also relevant. Specific questions concern how the presence of one species impacts the presence of another. For example, the Portland District USACE are particularly interested in how the presence of grass species impacts the establishment of woody species such as trees and shrubs, as well as the role that leguminous species play in plant establishment.

The historical development and evolution of vegetation is also of interest. This is addressed through a qualitative, visual assessment of aerial photographs covering the ELJ and Control Study Sites. The historical summary documents changes in vegetation between 2007 and 2013 (aerial photographs for 2008 do not exist); that is from three years prior to installation of the ELJs to three years after, in both the ELJ and Control Study Sites.

In detail, the biotic studies investigated the following questions:

1. What are the plant species compositions within the ELJ and Control Study Sites?
2. Do plant assemblages remain the same/similar across the sediment plain?
3. What are the percent vegetation cover, species abundance, and species diversity values at each ELJ?
4. Does the proximity of an active sub-channel of the NFTR affect vegetation percentage cover?

5. Is the vegetation on islands in the ELJ Study Site successfully trapping and retaining sediment, storing sand, and building grade?
6. Does distance from the valley side impact vegetation percentage cover?
7. Does the presence of grass species have any impact on presence of woody species?
8. Does the presence of leguminous species impact percent vegetation cover?
9. Has vegetation cover increased since installation of the ELJ structures?

3. Study Design and Field Methods

3.1 Study Design

Study design and data collection methods benefitted from input and support from Dr. Joe Maser, Dr. Yangdong Pan, Dr. Alan Yeakley at Portland State University, and from Tina Teed (Portland District, USACE Environmental Resource Specialist). Additionally, this research followed the transect methodology established in 2003 by Noah Jenkins, whose research was supervised by Alan Yeakley and Elaine Stewart (Jenkins 2005, Jenkins et al. 2008), and repeated in 2008 and in 2009 by Tina Schantz Farrelly (Farrelly, 2012).

The physical extents of the ELJ Study Site and Control Study Site were determined through site reconnaissance. The result of the site reconnaissance was delineation of the physical extents of the ELJ Study Site and Control Study Site. The ELJ Study Site was the area immediately around the structures that has been most directly impacted by their introduction and continuing presence. The Control Study Site was selected to represent an area of the sediment plain that had been relatively unaffected by the Grade Building Structures, while still being somewhat comparable to the ELJ Study Site, and within the AoI (for logistical practicality). The Control Study Site also included a “wall-based channel” that represented the contrasting conditions encountered in channels close to valley sides of the ELJ Study Site (Fig. 3.1). The dimensions for each extend was 700 ft wide and 1,800 ft long.

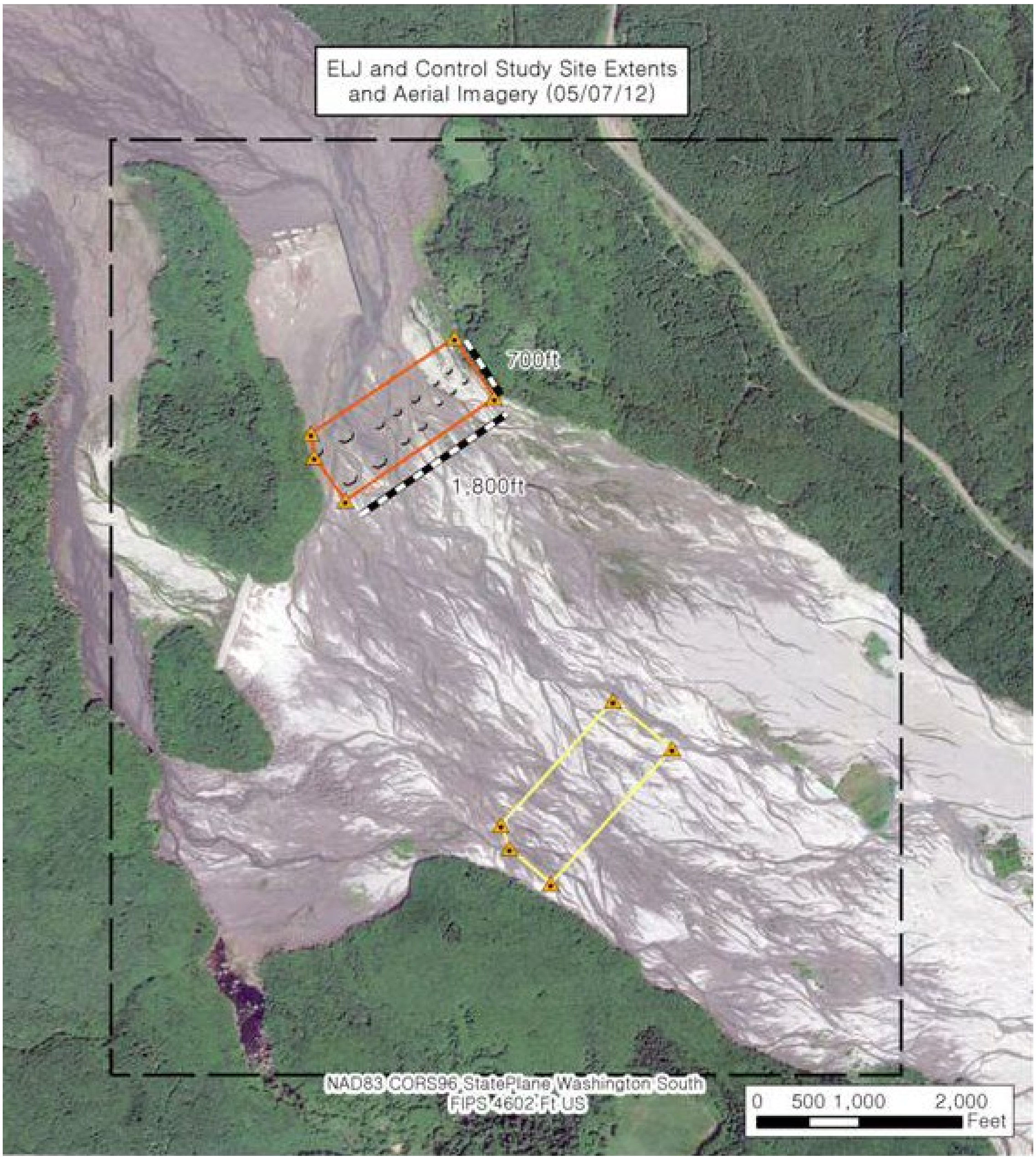


Figure 3.1 Map showing the Study Sites: Red = ELJ Study Site, yellow = Control Study Site.

Within the ELJ Study Site, individual study areas were created for each ELJ. These were designed to reflect the "Influence Zone" of each structure. The long-stream extent of the influence zone was estimated based on flow theory. On this basis, Dr. Thorne and the USACE Portland District estimated that the influence zone would extend downstream approximately one and a half times the width of the structure (Figure 3.2).

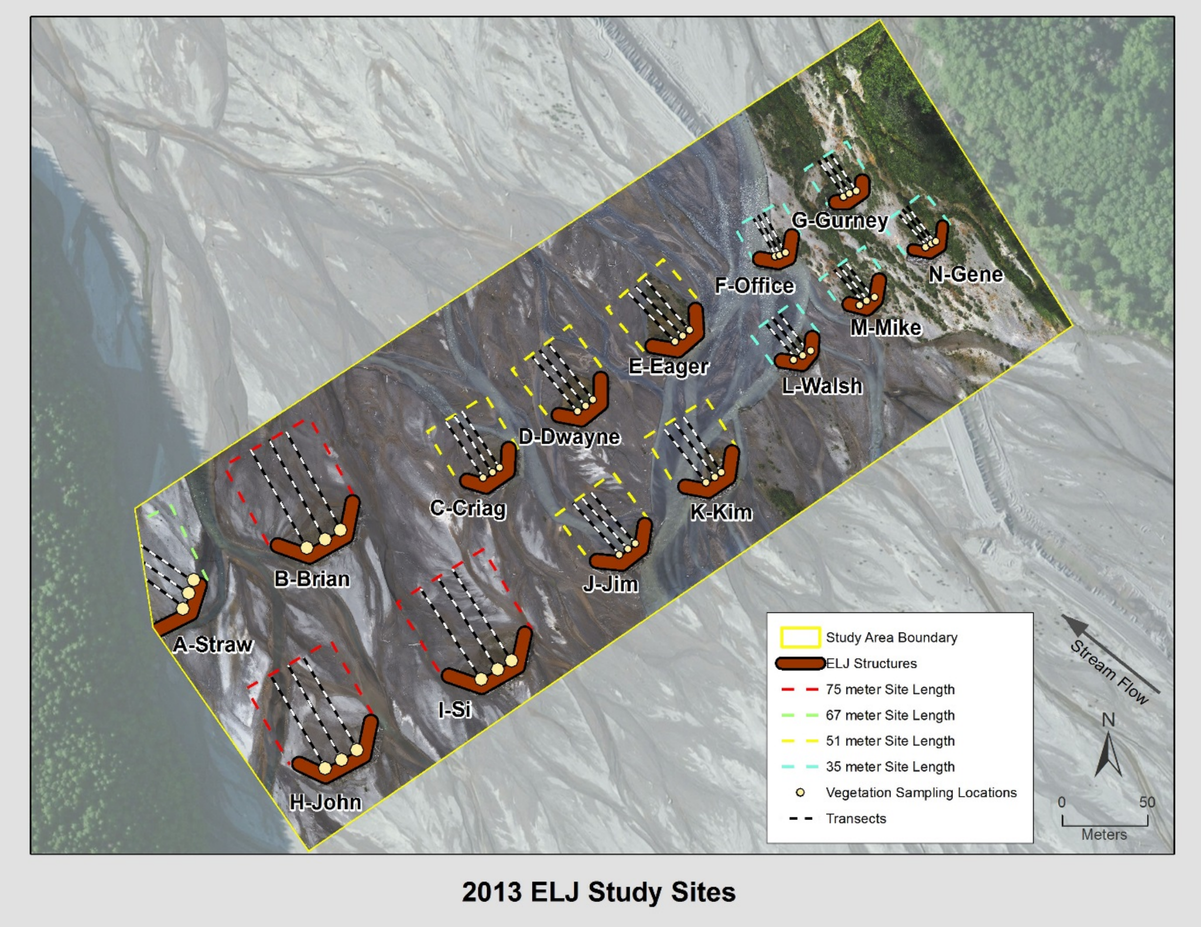


Figure 3.2 ELJ Study Site design map showing study area boundaries and transects for each ELJ.

Vegetation transects and sampling locations were designed to be in locations representative of the area behind the central part of the structure, rather than the wings (Figure 3.2). For structure Type A, this is represented by front posts three and six (post were numbered sequentially from South to North), and half way between posts four and five. For structure Type B, the sampling locations are represented by posts four and nine, and halfway between posts six and seven. For structure Type C, the sampling locations are represented by posts six, ten, and fourteen. For the structure known as “Straw”, posts six, ten, and fourteen were used as the sampling point locations. It should be noted that due to Straw’s close proximity to the valley wall it was not possible to extend the sampling transects the full 67 meters required to represent the influence zone. Instead, sampling was conducted until each transect reached the valley wall. Transect 1: 56.5 meters, Transect 2: 55.5, Transect 3: 66 meters.

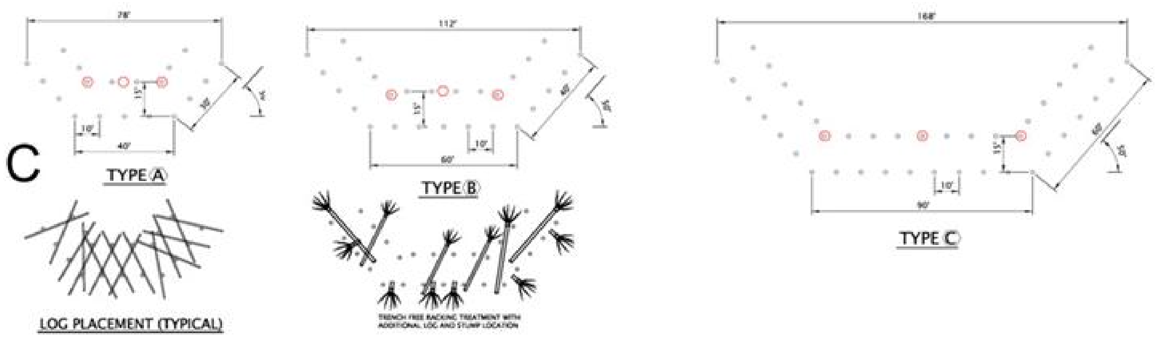


Figure 3.3 Vegetation transect start points were at the piles circled in red.

In practice, due to deterioration in the condition of several of the structures and the resulting vegetative responses, it was not always possible to position the transects according to these rules and still accurately characterize the vegetation (the goal of this study). This was true for structures Jim, Kim, and Office. For example, at ELJ Jim, the vegetated area was so heavily eroded that only two, repositioned transects were possible. The vegetation recorded on transects produced under these conditions was not included in vegetation percent cover estimates presented in this chapter. Instead a value of zero was entered when a transect could not be located correctly.

To set out transects in the Control Site at locations equivalent to those in the ELJ Site, the global navigation satellite system (GNSS) grid coordinates for the ELJ structures were downloaded into ArcMap and then transposed into the Control Study Site. The center point of each structure was used as the starting point for the equivalent transect in the Control Site.

Vegetation data were collected along a total of 56 transects, 3 transects x 14 structures = 42 transects within the Study Site and 14 structure-equivalent transects within the Control Site. Transects were labelled by site name and numbered sequentially from South to North.

The difference in the number of transects sampled in the two areas makes true comparison difficult, but the Study Site was the primary focus of this research and consequently it was the focus in terms of time and resources. Vegetation was surveyed during July, 2013. To set out each transect, a 50-meter tape was laid out between 14-inch survey pins perpendicular to the front of the ELJ, using the Garmin GNSS and/or a compass to set the correct heading for the transect. When it was windy additional survey pins were used to keep the tape in place. Most of the surveys were performed by Todd Ashley working alone, though Keston Keuchel provided assistance with some transects. All live vegetation that intersected a plumb line below, or a theoretical vertical line above, the transect was recorded at decimeter intervals along the tape. For the transects longer than 50 meters (i.e. Structure Types B, C, and Straw), it was necessary to re-string the tape following the same orientation, from the 50 meter survey pin to a pin placed at the end of the transect. All plants observed were recorded in a "Rite in the Rain" All-Weather Journal, following the methods used by Tina Schantz Farrelly (Farrelly, 2012). Occasionally it was not possible to identify a plant species in the field. When this issue arose the individual plant was photographed and a sample was taken for later identification. Samples were taken with roots intact whenever possible, placed in a Ziploc® bag and stored in a cooler until they could be identified at Portland State University. Many plant identification resources were used in the field and in the lab including:

Christy, John A. 2004. Native freshwater wetland plant associations of northwestern Oregon.

DiTomaso, J. M. and Evelyn A. Healy. 2003. Aquatic and Riparian Weeds of the West. University of California Agriculture and Natural Resources, Oakland, CA.

Guard, B. Jennifer. 1995. Wetland Plants of Oregon and Washington. Lone Pine Publ., Renton, WA

Hitchcock, C.L. and Cronquist, A. 1990. Flora of the Pacific Northwest. Univ. Washington Press, Seattle.

Oregon Natural Heritage Information Center, Oregon State University.Cooke, S. S. 1997. A Field Guide to the Common Wetland Plants of Western Washington and Northwestern Oregon. Seattle Audubon Society, Seattle, WA.

Pojar, J., MacKinnon, A. 1994. Plants of the Pacific Northwest Coast. Lone Pine Publ. Vancouver, B.C

Vegetation was often at different phenological stages and individuals could not always be identified to the species level. When species-level identification was not possible, individuals were identified to the genus level. Due to the time intensive nature of identifying grass species, it was sometimes necessary to identify grasses only to the family level. Individuals in very early cotyledon stage or those that were damaged beyond recognition were recorded as "unknown" or "seedling" according to the convention developed by Farrelly (2012).

3.2 Transect Data Entry

Raw vegetation data was entered in Excel, with each transect given its own "sheet". Data was entered using the "stacking method" recommended by Dr. Yandong Pan, wherein transect data were placed in columns. Transect data were combined to create a presence/absence database, which was used to determine percentage cover estimates for each species and Study Site, as well as to track additional variables.

RStudio software (RStudio, 2012) was used to:

- calculate species richness, species diversity, and Shannon-Wiener Diversity Index;
- complete cluster analyses on species and sites;
- perform Non-Metric Multidimensional Scaling (NMDS) of species and site, and;
- run Pearson Correlation analyses to investigate species to species and site to physical features relationships.

A Stream Channel Proximity Map was created by using the “buffer” tool in ArcMap to create exact buffers corresponding to each Type of ELJ. Each ELJ was individually buffered to serve as a "clip feature" for digitized channels. Digitized channels were then clipped, creating new feature classes of the channels solely in each individual buffer area.

3.3 Sediment Sampling

The USACE requested that a sediment sample be taken for each ELJ structure for future analysis. As the sediment was loosely compacted, a sediment corer was not required, and grab samples of surface sediment were taken at the beginning of transect one, the midway point of transect two, and at the end of transect three for each structure. The three samples taken at each structure were aggregated into a single Ziploc® bag to produce a single sediment sample for each ELJ. The sediment samples were delivered to Tina Teed for future analysis.

4. Identified Plant Species

The plant species and genera (when it was not possible to identify to species level) data recorded along all transects in the ELJ and Control Sites are listed in Table 4.1. This table lists the scientific name, species code used in the field, common name, native status, and wetland indicator status for each entry (USACE, 2014).

Table 4.1 Identified Plant Species (green = native, pink = non-native)

Species Code	Species	Common Name	Status	Indicator
AGST	*Agrostis stolonifera*	Creeping Bentgrass	Non-Native	FAC
AGTE	*Agrostis tenuis*	Colonial Bentgrass	Non-Native	FAC
ALRU	*Alnus rubra*	Red Alder	Native	FAC
ANMA	*Anaphalis margaritacea*	Pearly Everlasting	Native	FACU
CAST	*Carex stipata*	Sawbeak Sedge	Native	OBL
Carex	*Carex* spp.	--	Native	--

Caryophyllaceae	*Caryophyllaceae* spp.	--	Unknown	--
Chamaesyce	*Chamaesyce* spp.	--	Unknown	--
CIAR	*Cirsium arvense*	Canada Thistle	Non-Native	FAC
CYSC	*Cytisus scoparius*	Scotch Broom	Non-Native	UPL
DIPU	*Digitalis purpurea*	Common Foxglove	Non-Native	FACU
EPBR	*Epilobium brachycarpum*	Tall Annual Willowherb	Native	UPL
EPCI	*Epilobium ciliatum*	Fringed Willowherb	Native	FACW
Epilobium	*Epilobium* spp.	--	Unknown	--
EQAR	*Equisetum arvense*	Common Horsetail	Native	FAC
EQHY	*Equisetum hyemale*	Scouring Rush Horsetail	Native	FACW
Euphorbia	*Euphorbia spp.*	--	Unknown	--
HOLA	*Holcus lanatus*	Common Velvetgrass	Non-Native	FAC
HYRA	*Hypochaeris radicata*	Hairy Cat's Ear	Non-native	FACU
JUAC	*Juncus acuminatus*	Tapered Rush	Native	OBL
JUBU	*Juncus bufonius*	Toad Rush	Native	FACW
JUEF	*Juncus effusus*	Common Rush	Native	FACW
JUEN	*Juncus ensifolius*	Swordleaf Rush	Native	FACW
JUME	*Juncus mertensianus*	Merten's Rush	Native	OBL
Juncus	*Juncus* spp.	--	Native	--
JUTE	*Juncus tenuis*	Slender Rush	Native	FAC
LOCO	*Lotus corniculatus*	Birdsfoot Trefoil	Non-Native	FAC
LOMI	*Lotus micranthus*	Small-Flowered Lotus	Native	FAC
LOMU	*Lolium multiflorum*	Italian Rye Grass	Non-Native	FAC
LUPO	*Lupinus polyphyllus*	Large-Leaved Lupine	Native	FAC
MIGU	*Mimulus guttatus*	Yellow Monkeyflower	Native	OBL
Mimulus	*Mimulus* spp.	--	Unknown	
PAVI	*Parentucellia viscosa*	Yellow Glandweed	Non-Native	FAC
PHAR	*Phalaris arundinacea*	Reed Canary Grass	Non-Native	FACW

PLMA	*Plantago major*	Common Plantain	Non-native	FAC
POBA	*Populus balsamifera*	Black Cottonwood	Native	FAC
POMO	*Polypogon monspeliensis*	Annual Rabbitsfoot Grass	Non-Native	FACW
PSST	*Pseudognaphalium stramineum*	Cottonbatting Plant	Native	FAC
RUAC	*Rumex acetosella*	Sheep's Sorrel	Non-Native	FACU
RUCR	*Rumex crispus*	Curly Dock	Non-Native	FAC
RULA	*Rubus laciniatus*	Cutleaf Blackberry	Non-Native	FACU
RUOB	*Rumex obtusifolius*	Broadleaf Dock	Non-Native	FAC
RUOC	*Rumex occidentalis*	Western Dock	Non-Native	FACW
Salix	*Salix* spp.	--	Unknown	
SCTA	*Schoenoplectus tabernaemontani*	Softstem Bulrush	Native	OBL
SESY	*Senecio sylvaticus*	Wood Groundsel	Non-Native	FACU
SEVU	*Senecio vulgaris*	Old -Man-In-The-Spring	Non-Native	FACU
Trifolium	*Trifolium* spp.	--	Unknown	
TRRE	*Trifolium repens*	White Clover	Non-Native	FAC
URDI	*Urtica dioica*	Stinging Nettle	Native	FAC
VISA	*Vicia sativa*	Common Vetch	Non-Native	UPL

Along the 56 total transects, 42 individual plants were recorded that could be identified to species level. Plants that could not be identified to the species level were identified to the genus level, except for some of the grass specimens that could only be identified to family level, *Poaceae*. It was believed that genera within the grass family that were encountered, but could not be identified include *Bromus*, *Phleum*, and *Festuca*. Individuals from the *Agrostis* genus were common, but due to hybridization that occurs within the genus it was seldom feasible to differentiate between *Agrostis scabra, Agrostis tenius,* or other varieties of bentgrass. Due to its creeping nature, it was possible to identify *Agrostis stolonifera* to species level without confusing it with other common *Agrostis* species, although it should be noted that it is known to hybridize with such species (Pojar, 1994).

Of the 42 identified plant species 20 were native species, while 22 were non-native species. Non-native plant establishment is not surprising as much of the surrounding landscape is private and state land managed for forestry that is inundated with non-native species. Additionally, in 1980 the Soil Conservation Service (renamed the Natural Resources Conservation Service) aerially distributed a seed mixture of mostly non-native herbaceous legumes and grass varieties in an effort to stabilize the western portion of the debris avalanche and the extending mudflow. It is encouraging to note that scientists researching Mount St. Helens have found no examples of exotic species dominating large areas of the disturbed landscape. Most of the non-native species found on the sediment plain are sun loving herbs, which will not likely have long term impact on native plant establishment (Dale, 2005).

5. Results for the Control Site

Estimates of percentage vegetation cover for each structure-equivalent transect in the Control Site are listed in Table 5.1, together with the average percentage vegetation cover for all transects.

Table 5.1 Control Area: Percentage Vegetation Cover

Transect (name indicates equivalent transect at ELJ study Site)	**Vegetation Cover (%)**	**Transect** (name indicates equivalent transect at ELJ study Site)	**Vegetation Cover (%)**
Straw Control	3	John Control	5
Brian Control	5	Si Control	10
Craig Control	2	Jim Control	19
Dwyane Control	5	Kim-Control	2
Eagar Control	46	Walsh Control	11
Office Control	1.5	Mike Control	0.3
Gurney Control	3	Gene Control	10
Average for all transects = 8.8%			

The average vegetation cover for the Control Sites was 8.8%, with the most vegetated site (Eagar Control) exhibiting 46% cover. However, Eagar Control was an outlier in that it had more than double the vegetated area of the second most vegetated transect (Jim Control, 19%). In fact, Eagar Control's vegetation cover was highly inflated by several large clumps of the aggressive, invasive plant *Cytisus scoparius* (Scotch Broom), which covered 26% of the transect. If Eagar Control is excluded from the analysis, the average percentage cover for the Control Sites falls to 5.9%.

Species recorded along transects in the Control Area are listed in Table 4.3, together with their frequency of occurrence (out of a possible 7,220 occurrences).

Table 5.2 Control Site: Individual Vegetation Species Occurrence

Species Code	Species	Common Name	**Frequency of occurrence** (6,200 possible occurences)
CYSC	*Cytisus scoparius*	Scotch Broom	137
ALRU	*Alnus rubra*	Red Alder	133
PHAR	*Phalaris arundinacea*	Reed Canary Grass	90
LUPO	*Lupinus polyphyllus*	Large-Leaved Lupine	43
LOMI	*Lotus micranthus*	Small-Flowered Lotus	40
JUBU	*Juncus bufonius*	Toad Rush	35
EQAR	*Equisetum arvense*	Common Horsetail	24
Agrostis	Agrostis *spp.*	--	22
AGST	*Agrostis tenius*	Colonial Bentgrass	22
LOCO	*Lotus corniculatus*	Birdsfoot Trefoil	17
RUAC	*Rumex acetosella*	Sheep's Sorrel	16
Juncus	*Juncus spp.*	--	15
Salix	*Salix spp.*	--	44
Unknown Epilobium	*Epilobium spp.*	--	8
Unknown Grass	--	--	8
POBA	*Populus balsamifera*	Black Cottonwood	7
Carex	*Carex spp.*	--	6
PSST	*Pseudognaphalium stramineum*	Cottonbatting Plant	6
PLMA	*Plantago major*	Common Plantain	4
TRRE	*Trifolium repens*	White Clover	4
Unknown	--	--	4
JUAC	*Juncus acuminatus*	Tapered Rush	3
Chamaesyce *spp.*	Chamaesyce *spp.*	--	2
EPCI	*Epilobium ciliatum*	Fringed Willowherb	2
HYRA	*Hypochaeris radicata*	Hairy Cat's Ear	2
LOMU	*Lolium multiflorum*	Italian Rye Grass	2
Seedling	--	--	2
ANMA	*Anaphalis margaritacea*	Pearly Everlasting	1
EPBR	*Epilobium brachycarpum*	Tall Annual Willowherb	1
HOLA	*Holcus lanatus*	Common Velvetgrass	1
Iris	*Iris spp.*	--	1
JUEF	*Juncus effusus*	Common Rush	1
JUEN	*Juncus ensifolius*	Swordleaf Rush	1
Mimulus	*Mimulus* spp.	--	1

Cytisus scopariu was the most abundant species recorded along the structure equivalent transects in the Control Site. This is again due to its dominance along the Eagar Control transect. *Alnus rubra* was the next most abundant species but unlike *Cytisus scopariu* it was widespread, being present along 10 of the 14 transects in the Control Site.

Table 5.3 lists species richness values for structure equivalent transects in the Control Site.

Table 5.3 Control Site: Vegetation Species Richness

Transect (name indicates equivalent transect at ELJ study Site)	**Species Richness**	**Transect** (name indicates equivalent transect at ELJ study Site)	**Species Richness**
Straw Control	11	John Control	
Brian Control	14	Si Control	13
Craig Control	8	Jim Control	7
Dwayne Control	8	Kim-Control	7
Eagar Control	18	Walsh Control	11
Office Control	3	Mike Control	2
Gurney Control	5	Gene Control	11
Mean and S.D. = 9.1 +/- 4.3			

Eagar Control was the most species-rich transect, with 18 entries. The mean species richness for all the transects in the Control Site is 9.14, with a standard deviation of 4.34.

Table 5.4 lists values of the Shannon-Weiner Diversity Index for each transect the Control Site.

Table 5.4 Control Site: Vegetation Diversity

Transect (name indicates equivalent transect at ELJ study Site)	**Shannon-Weiner Diversity Index**	**Transect** (name indicates equivalent transect at ELJ study Site)	**Shannon-Weiner Diversity Index**
Straw Control	2.24	John Control	1.81
Brian Control	2.37	Si Control	1.21
Craig Control	2.00	Jim Control	1.88
Dwayne Control	1.88	Kim-Control	1.76
Eagar Control	1.93	Walsh Control	1.86
Office Control	1.01	Mike Control	0.69
Gurney Control	1.54	Gene Control	1.93
Average 1.72			

The ‘Brian Control’ transect exhibited the highest Shannon Diversity Index, while ‘Mike Control’ was the transect the lowest vegetation diversity in the Control Site.

6. Results for the ELJ Study Site

Percentage vegetation cover results for each structure in the ELJ Study Site are listed in table 6.1, together with the average percentage cover for all the structures.

Table 6.1 ELJ Study Site: Percentage Vegetation Cover

Structure	Vegetation Cover (%)	Structure	Vegetation Cover (%)
Straw	6	John	9
Brian	12	Si	13
Craig	15	Jim	3.2
Dwayne	30	Kim	19
Eagar	55	Walsh	14
Office	13	Mike	75
Gurney	72	Gene	70
Average for all structures = 29.01%			

The average percent cover of vegetation for islands behind structures in the ELJ Study Site was 29.01%, with the most vegetated structure (Mike) having 75% vegetation cover. The patchy vegetation cover in the ELJ Study Site is not far off from the 38% vegetation cover average found along transects in similarly disturbed areas near Mount St. Helens (Dale, 1989). Three structures had particularly high percentage covers equal to or greater than 70%: Mike, Gene and Gurney. Significantly, these are all located in the proto-floodplain that is developing along the Northern fringe of the sediment plain in the AoI, which has not been disturbed by sub-channels of the NFTR since the structures were constructed in 2010, but which receives sediment-free water from the local drainage network developing on it because it conveys runoff from Hoffstadt Creek, valley side springs and exfiltrating groundwater.

Table 6.2 lists all species recorded along transects in the ELJ Study Site, together with their frequencies of occurrence. Species with the ability to fix nitrogen are highlighted in yellow.

Table 6.2 ELJ Study Site: Individual Species Occurrence

Species Code	Species	Common Name	Frequency of occurrence (20,915 possible occurrences)
ALRU	*Alnus rubra*	Red Alder	2342
PHAR	*Phalaris arundinacea*	Reed Canary Grass	846
LOCO	*Lotus corniculatus*	Birdsfoot Trefoil	647
JUBU	*Juncus bufonius*	Toad Rush	525
LOMI	*Lotus micranthus*	Small-Flowered Lotus	412
EQAR	*Equisetum arvense*	Common Horsetail	317

Agrostis spp.	*Agrostis* spp.	--	268
JUEF	*Juncus effusus*	Common Rush	251
Grass	--	--	240
JUAC	*Juncus acuminatus*	Tapered Rush	216
JUEN	*Juncus ensifolius*	Swordleaf Rush	190
TRRE	*Trifolium repens*	White Clover	147
EPCI	*Epilobium ciliatum*	Fringed Willowherb	138
Salix spp.	Salix spp.	--	238
EPBR	*Epilobium brachycarpum*	Tall Annual Willowherb	100
LOMU	*Lolium multiflorum*	Italian Rye Grass	97
RUAC	*Rumex acetosella*	Sheep's Sorrel	80
HOLA	*Holcus lanatus*	Common Velvetgrass	68
Juncus spp.	Juncus spp.	--	65
ANMA	*Anaphalis margaritacea*	Pearly Everlasting	53
AGST	*Agrostis tenius*	Colonial Bentgrass	49
HYRA	*Hypochaeris radicata*	Hairy Cat's Ear	44
SEVU	*Senecio vulgaris*	Old -Man-In-The-Spring	33
POMO	*Polypogon monspeliensis*	Annual Rabbitsfoot Grass	21
LUPO	*Lupinus polyphyllus*	Large-Leaved Lupine	20
POBA	*Populus balsamifera*	Black Cottonwood	18
Caryophyllaceae spp.	Caryophyllaceae spp	--	17
PSST	*Pseudognaphalium stramineum*	Cottonbatting Plant	16
Unknown	--	--	16
EQHY	*Equisetum hyemale*	Scouring Rush Horsetail	14
CIAR	*Cirsium arvense*	Canada Thistle	13
JUTE	*Juncus tenuis*	Slender Rush	12
Epilobium	Unknown Epilobium	--	11
DIPU	*Digitalis purpurea*	Common Foxglove	10
Seedling	Unknown Seedling	--	9
AGTE	*Agrostis tenius*	Colonial Bentgrass	8
SESY	*Senecio sylvaticus*	Wood Groundsel	8
Carex spp.	Carex spp.	--	7
SCTA	*Schoenoplectus tabernaemontani*	Softstem Bulrush	7
JUME	*Juncus mertensianus*	Merten's Rush	5
VISA	*Vicia sativa*	Common Vetch	4
CAST	*Carex stipata*	Sawbeak Sedge	3
RUOB	*Rumex obtusifolius*	Broadleaf Dock	3
CYSC	*Cytisus scoparius*	Scotch Broom	2
PAVI	*Parentucellia viscosa*	Yellow Glandweed	2
Trifolium	--	--	2
Iris	--	--	1
MIGU	*Mimulus guttatus*	Yellow Monkeyflower	1
RUCR	*Rumex crispus*	Curly Dock	1

RULA	*Rubus laciniatus*	Cutleaf Blackberry	1
RUOC	*Rumex occidentalis*	Western Dock	1
URDI	*Urtica dioica*	Stinging Nettle	1

Alnus rubra is by far the most abundant species in the ELJ Study Site, and it is more than two and a half times more abundant than the next genus/species. This is not surprising as other studies have shown that *Alnus rubra* is also the most dominant species upstream from the AoI on the debris avalanche (Dale, 2005). It is important to note this is one of the species highlighted in yellow in Table 6.2 – that is, it has the ability to fix nitrogen and is well adapted for colonising nutrient-poor areas, such as the sediment plain. In fact, three of the top five most abundant species present behind the ELJ structures are those associated with nitrogen fixing bacteria, (see Table 6.2), which indicates that this ability gives these plants a considerable advantage, as it has been documented further upstream, in colonising the sediment plain as pioneer species (Dale, 2005).

Table 6.3 lists the species richness values for transects downstream of the structures in the ELJ Study Site.

Table 6.3 Study Area Species Richness

Structure	Species Richness	Structure	Species Richness
Straw	16	John	16
Brian	15	Si	17
Craig	15	Jim	16
Dwayne	22	Kim	25
Eagar	38	Walsh	15
Office	14	Mike	24
Gurney	27	Gene	24
Mean and S.D. = 20.3 +/-6.8			

Eagar was the most species-rich ELJ, with 38 different genera/species being sampled. The mean species richness for all the structures in ELJ Study Site is 20.3, with a relative high standard deviation of 6.79. Both the mean and standard deviation are higher than the equivalent figures for the Control Site, this indicates that vegetation species were richer but varied more between transects.

Table 4.9 lists the Shannon-Weiner Diversity Index values for transects in the ELJ Study Site.

Table 6.4 ELJ Study Site: Vegetation Diversity

Structure	Shannon-Weiner Diversity Index	Structure	Shannon-Weiner Diversity Index
Straw	1.94	John	1.97
Brian	2.00	Si	2.27
Craig	2.04	Jim	2.12
Dwayne	2.25	Kim	2.45
Eagar	2.63	Walsh	1.56
Office	1.88	Mike	1.69
Gurney	1.84	Gene	2.14
Average for all structures = 2.05			

The structure 'Eagar' also exhibited the highest Shannon Diversity Index (2.63) of all the transects sampled in the ELJ Study Area, while the structure 'Walsh' (1.56) had the least diverse vegetation.

7. Characterization of Plant Assemblages

The pie chart in Fig. 7.1 illustrates the distribution of broad vegetation types in the Control Site.

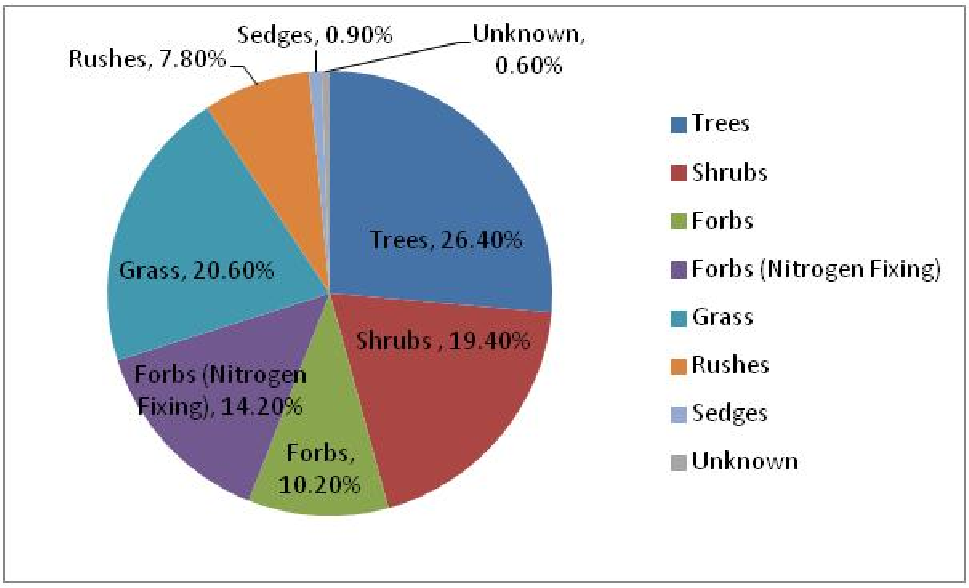


Figure 7.1 Vegetation Types sampled in the Control Site. The vegetation type classification used was requested by the USACE.

Trees, primarily *Alnus rubra*, are the dominate type of vegetation in the Control Site. Although "shrubs" make up almost 20% of the plant community in the Control Site, only a single shrub species was actually present. This was *Cytisus scoparius* (Scotch Broom), which is undesirable because it is a highly invasive non-native species known to contribute to reductions in plant community diversity (Montana State University, 2010).

The pie chart in Fig. 7.2 illustrates the distribution of vegetation types in the ELJ Study Site.

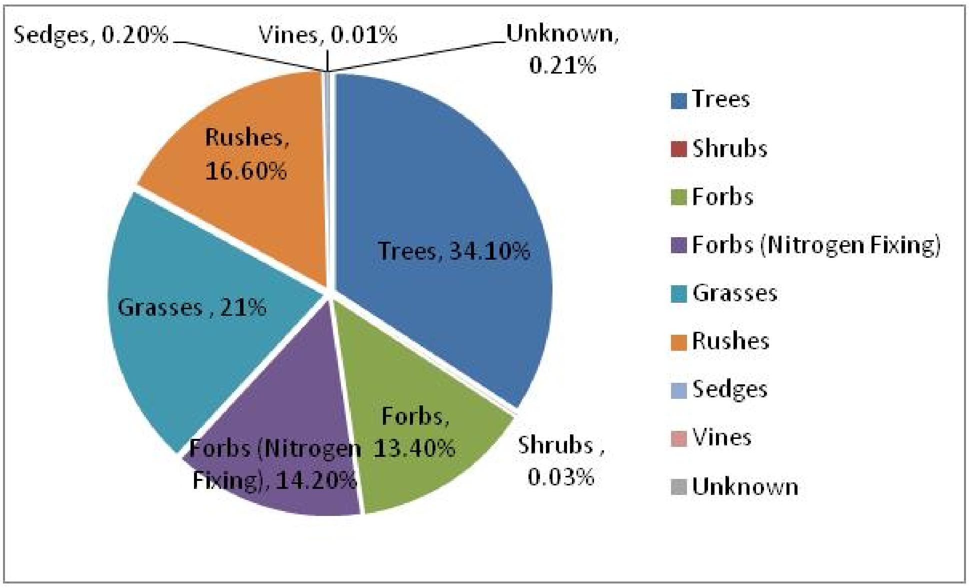


Figure 7.2 Vegetation Types sampled in the ELJ Study Site. The vegetation type classification used was requested by the USACE.

Trees (mostly *Alnus rubra* as found in the Control Site) are even more dominant in the ELJ Study Site. There are virtually no shrubs in the ELJ Study Site, which is a marked contrast to the Control Site. This is because the large patches of *Cytisus scoparius* found in the Control Site are absent from the ELJ Study Site. Hence, this is of benefit to the ELJ Study Site that this invasive, non-native species has yet to successfully establish.

Figs. 7.1 and 7.2 characterize the plant composition through broad vegetation type classification, which is the way that vegetation on the sediment plain will probably be monitored in the future. However, for the purpose of the biotic study it was also necessary to investigate and summarize more detailed, species-level interactions.

Figure 7.3 displays the results of an NMDS ordination of all the species recorded along transects in the ELJ and Control Sites. This plot provides a visual representation of species to species relationships. Essentially, the closer species are to one another in the ordination plot, the more likely they are to occur together on the sediment plain.

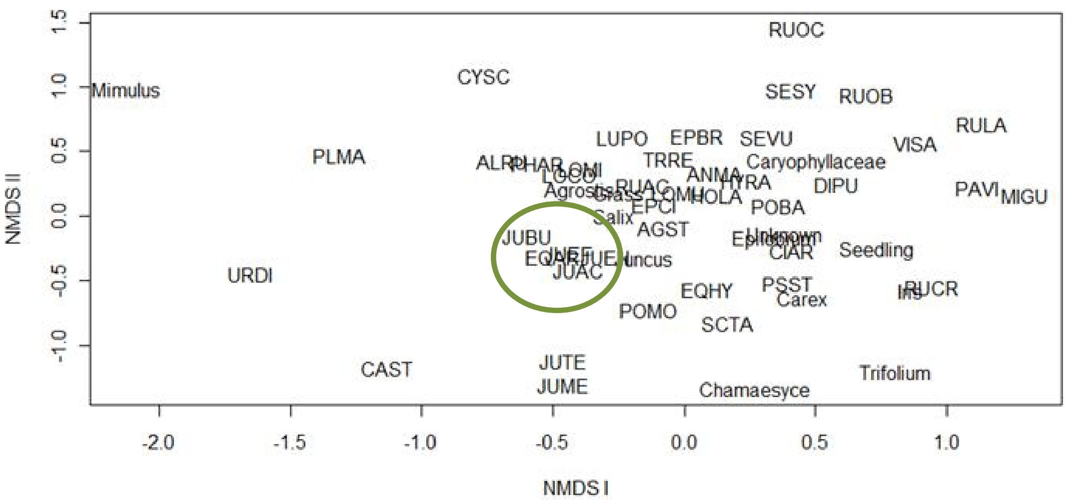


Figure 7.3 Plant Species NMDS for all transects sampled on the sediment plain.

Figure 7.3 indicates that plant species composition remains broadly similar across the sediment plain. The ordination shows substantial "stacking" as well as minimal distance between the majority of species shown. The main congregation of species does not indicate a specific dominate vegetation type as it includes everything from obligate wetland species to upland species. The species that lie outside of the main grouping are low occurrence species that were only encountered at two or less study sites and with very minimal cover (Table 7.1).

Simply stated, most species encountered were found at all study sites. There is some separate grouping of wetland indicator species, primarily from *Juncus* genus (circled in green), but overall species do not fluctuate all that much across the study sites.

Table 7.1 Low Occurrence Specie

Species Code	Species	Common Name
CAST	*Carex stipata*	Sawbeak Sedge
DIPU	*Digitalis purpurea*	Common Foxglove
MIGU	*Mimulus guttatus*	Yellow Monkeyflower
Mimulus	*Mimulus* spp.	--
PAVI	*Parentucellia viscosa*	Yellow Glandweed
RULA	*Rubus laciniatus*	Cutleaf Blackberry

RUOB	*Rumex obtusifolius*	Broadleaf Dock
RUOC	*Rumex occidentalis*	Western Dock
SESY	*Senecio sylvaticus*	Wood Groundsel
Trifolium	*Trifolium* spp.	--
URDI	*Urtica dioica*	Stinging Nettle
VISA	*Vicia sativa*	Common Vetch

Within the limited species variation across the sediment plain there were observable differences from site to site, particularly in the Study Area. Figure 7.4 displays the results of NMDS ordination of the structures in the ELJ Study Site together with the equivalent transects in the Control Study Site.

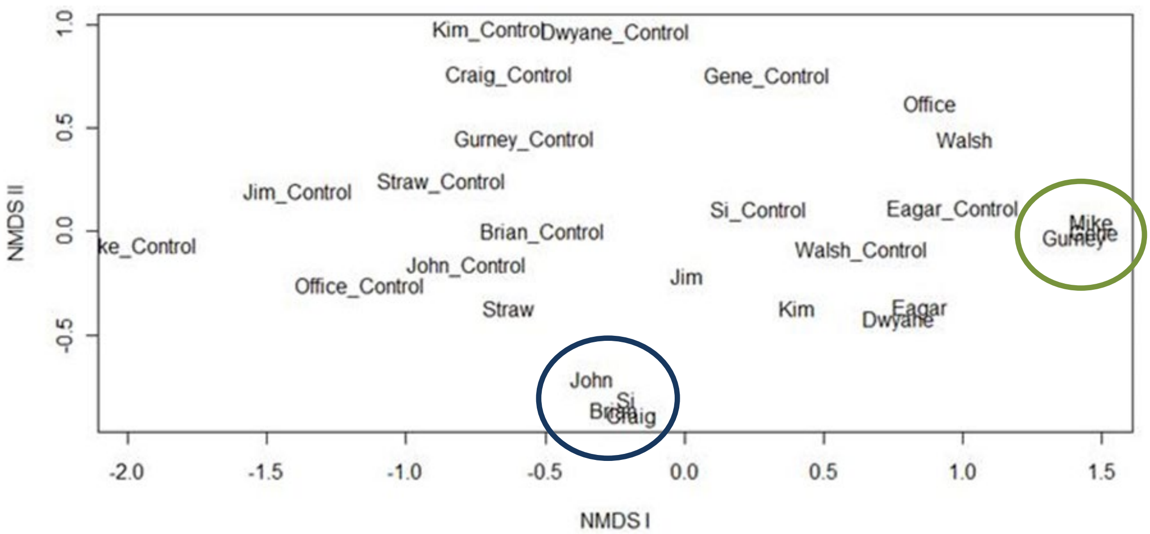


Figure 7.4 NMDS for all Study Sites and Equivalent Transects.

The NMDS plot gives a visual representation of the similarity between the different structures and transects: the closer they are to one another, the more similar are their plant assemblages. A degree of clustering is evident in Fig. 7.4. For example, ELJs Mike, Gene, and Gurney (circled in green) cluster together in the far right of the ordination plot. These structures essentially stack on top of each, indicating that their plant assemblages, which contained several FACU and UPL species, are virtually identical. Structures John, Si, Brian, and Craig (circled in blue) also stack on top of each other, but they are widely separated from Mike, Gene and Gurney, which is as expected given that plant assemblages behind these structures contained no UPL species and higher proportion of wetland indicator species. These similarities and differences in species composition are explained by the fact that structures within the clusters are located in close physical proximity while there is a considerable distance between structures in different clusters.

Hence, the clusters featuring predominantly 'upland' plants are positioned on the proto-floodplain that runs along the Northern third of the sediment plain, close to the valley side, while the 'wetland' cluster is positioned to the south, in the area of the sediment plain that is lower, wetter and further away from valley side, and has been most recently occupied and actively reworked by the NFTR. The link between location on the ordination plot, plant assemblage, geographical position, and local environment also extends to structures proximal to clusters. For example, Straw is the closest structure to the 'wetland' cluster both physically and environmentally, while Walsh and Eagar/Dwayne are the closest structures to Mike, Gene and Gurney in the ELJ Study Site.

Fig. 7.5 displays the presence of obligate wetland species by % cover within the Study Area.

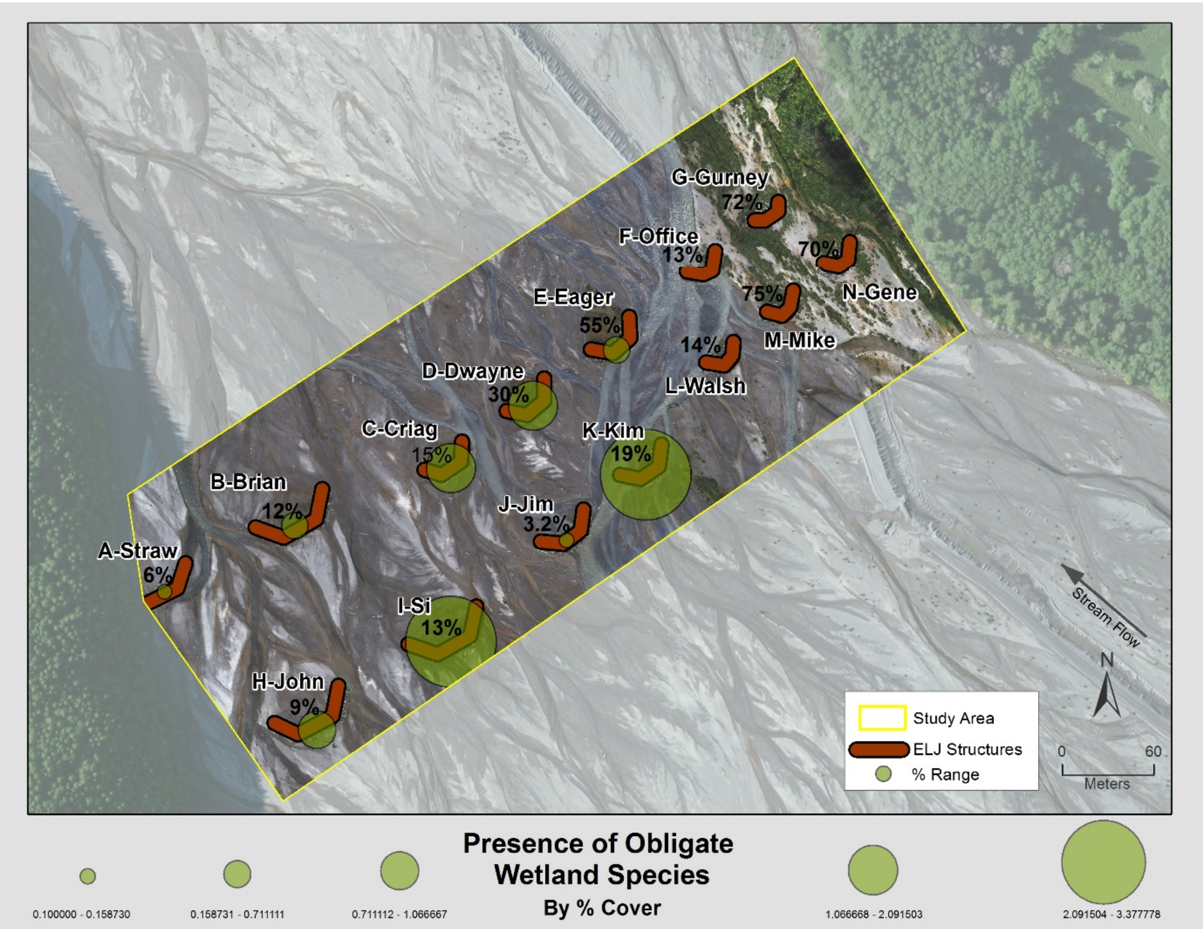


Figure 7.5 Presence of Obligate Wetland Species Map

The Presence of Obligate Wetland Species map further confirms the absence of obligate wetland species in the northern third of the sediment plain. Overall vegetation cover is shown for each structure, while the amount of obligate wetland species cover is shown using the green circles; the bigger the circle, the more obligate wetland species cover there is. Established OBL species include *Carex stipata*, *Juncus acuminatus*, *Juncus mertensianus*, and *Schoenoplectus tabernaemontani*.

In summary, while the NMDS analysis and the Presence of Obligate Wetland Species Map do reveal subtle variations in the distributions of species and assemblages across the sediment plain, the plants encountered along each transect are generally similar. Typically, most transects feature a dominant community of *Alnus rubra,* one or two leguminous forbs, a grass variety (typically *Phalaris arundinacea*), one or more obligated wetland species and (with the lowest abundance) a mix of disturbance-following non-leguminous forbs.

In this respect, the islands with the best overall performances in terms of percentage cover, species diversity, and species richness (Eagar and Kim) are illustrative (Table 7.2).

Table 7.2 Five most abundant species observed on the islands behind the Eagar and Kim ELJs

Eagar		**Kim**	
Species	Common name	Species	Common name
Alnus rubra	Red Alder	*Phalaris arundinacea*	Reed Canary Grass
Lotus corniculatus	Birdsfoot Trefoil	*Alnus rubra*	Red Alder
Phalaris arundinacea	Reed Canary Grass	*Juncus acuminatus*	Tapered Rush
Lotus micranthus	Small-Flowered Lotus	*Lotus corniculatus*	Birdsfoot Trefoil
Juncus bufonius	Toad Rush	*Juncus bufonius*	Toad Rush

The five most abundant species found at Kim and Eager are fundamentally similar, the difference being that Eagar supports two leguminous forbs, *Lotus corniculatus* and *Lotus micranthus*, while Kim supports two obligate wetland species, *Juncus acuminatus* and *Juncus bufonius*. These similarities in species composition are even more significant considering that the percentage cover at Eagar is more double that at Kim.

8. Spatial Distribution and the Physical Environment

With a better understanding of the plant assemblages sampled within the ELJ and Control Study Sites, further insights can be gained by examining spatial distributions and how plant establishments is impacted by stream channel activity, distance to valley edge, and sedimentation.

It was expected that plant types and assemblages in islands behind the ELJs would also be affected by disturbance and that this would be related to the number of actively migrating channels within the "influence area" for each structure. The presence of channels and the degree to which they were laterally active was established using the satellite images for 2011 to 2012 and the GIS platform ArcView (Fig. 4.9).

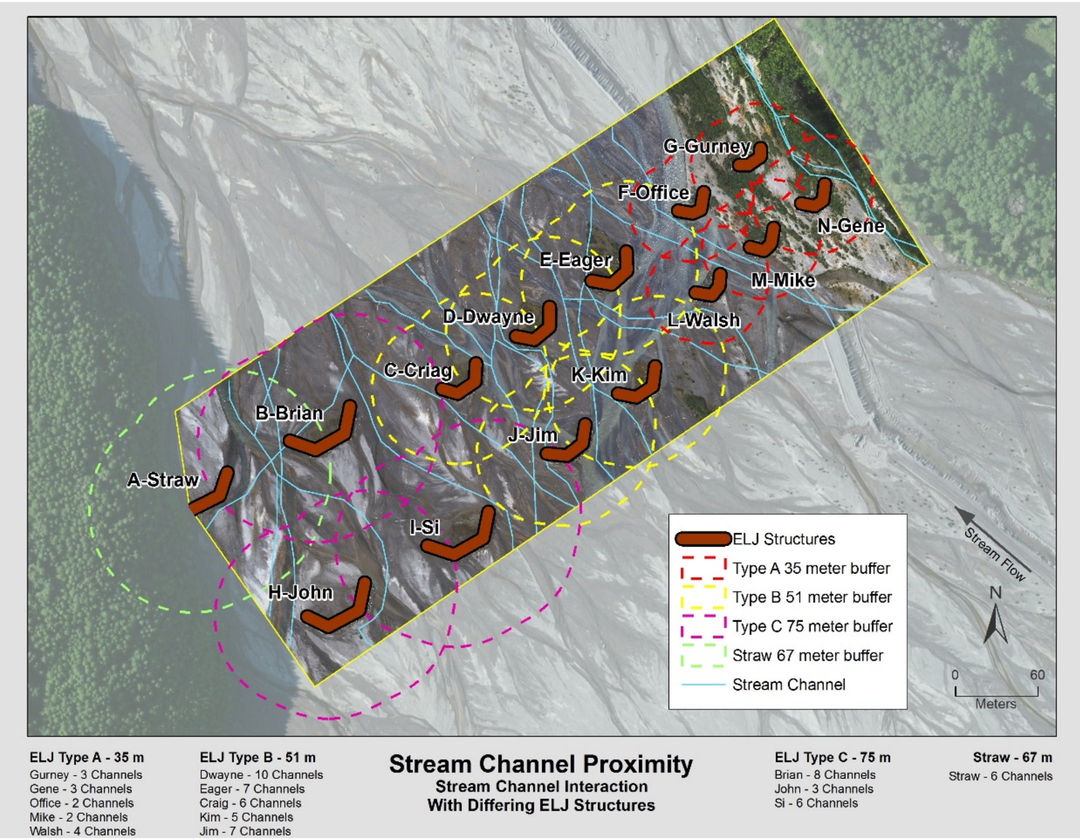


Figure 8.1 Map showing number and activity of channels in the ELJ Study Site between 2011 and 2012.

The Pearson Product Moment Correlation Coefficient for the relationship between the presence of active channels and the percentage of the influence area covered by vegetation is -0.28, which indicates a moderate, inverse relationship between the number of channels and percent vegetation cover. This is expected because as channel numbers and lateral activity increase, so does disturbance of the sediment plain, with vegetation being either prevented from establishing or being removed from within active channels and adjacent, eroded areas. The correlation coefficient was higher when the analysis was repeated for 2006 to 2012, perhaps indicating that vegetation cover decreases further when sites are disturbed on multiple occasions during a relatively short period. The stream channel proximity analysis is limited in that it does not take channel size into account, nor does it consider fluvial attributes that would obviously impact vegetation, including velocity. Additionally, since 2013 channel data is unavailable, this analysis leaves out the impacts of the most recent stream channels on vegetation.

It was also expected that percentage vegetation cover would decrease with increasing distance from the major seed source which, in the case of the sediment plain, is the nearest undisturbed valley side. This was tested by using the 'Distance Between Points' tool in ArcMap to establish the distance from the valley for each ELJ (Table 8.1) and then correlating this with the percentage vegetation cover.

Table 8.1 Distance from Valley Edge

Structure	Distance From Valley Edge (m)	Structure	Distance From Valley Edge (m)
Straw	25	John	95
Brian	120	Si	195
Craig	230	Jim	290
Dwayne	255	Kim	225
Eagar	185	Walsh	140
Office	110	Mike	90
Gurney	60	Gene	38

The Pearson Correlation value for distance to nearest valley side and percentage vegetation cover is -0.38, which indicates a moderate negative relationship. This is consistent with the hypothesis that the valley sides are the main source for seeds and plant propagules and that vegetation cover therefore decreases with distance from those sources. Conversely, previous studies on the debris avalanche have found that the number of seeds present and distance to surviving vegetation do not share a linear relationship. There is a general decrease in the number of seeds at a distance from seeds source greater than 1.1 km, but it has been found that seed dispersal is largely influenced by the attributes of the prevailing winds and not distance to seed source (Dale, 1989).

With *Phalaris arundinacea* (Reed Canary Grass) as the second most abundant species in the study areas there was concern that this highly invasive species could be inhibiting the establishment of woods tree species. The most abundant tree species on the sediment plain is clearly *Alnus rubra*, hence a correlation analysis was performed between *Alnus rubra* and *Phalaris arundinacea*. The correlation coefficient for this relationship is 0.72, which indicates a strong, positive relationship. This correlation provides no evidence that Reed Canary Grass is negatively impacting the establishment of Red Alder on the sediment plain. In fact, Red Alder has been documented to be successful in shading out Reed Canary Grass once is has a developed a closed canopy, usually after five years; so there is potential for *Phalaris arundinacea* cover to decrease over time (Tu, 2004).

There is particular interest in the spread of legumes on to the sediment plain because of their ability to improve soil conditions. Lupine has been documented to create microhabitats that are hospitable to other plant species in addition to its ability to chemically improve soil quality. Lupine also have the ability to attract insects and trap debris which ultimately enrich the soil. On the Mount St. Helens pumice plain Lupine patches in particular became biological hotspots as they attracted small mammals and birds, and facilitated the colonization of other plant species (Science Update, 2010).

The relationship between leguminous plant species and percentage cover within the ELJ Study Site was investigated. Statistically significant positive correlations with percentage cover were found for the three main legumes forbs present in the ELJ Study Area, *Lotus corniculatus*, *Lotus micranthus*, and *Trifolium repens*. This suggests that the presence of leguminous species makes it easier for other plant types and species to colonize a previously barren area of the sediment plain.

Sedimentation is, potentially, another source of disturbance. In this context, comparison of the DEMs for 2009 and 2012 (Fig. 8.2), reproduced below for convenience indicates that between 2009 and 2012, deposition occurred behind Straw, Brian, Craig, John, Si, erosion occurred behind Kim and Eagar, and there was net stability behind Dwayne, Office, Gurney, Jim, Walsh, Mike and Gene. However, it should be noted that in 2013 serious erosion that is not represented in Fig. 8.2 occurred behind Office and Walsh. The highest percentage covers are associated with stable sites. Disturbance by erosion or deposition tends to reduce plant cover, unless the ELJ structure is effective in sheltering the island from fluvial disturbance as is the case with Eager.

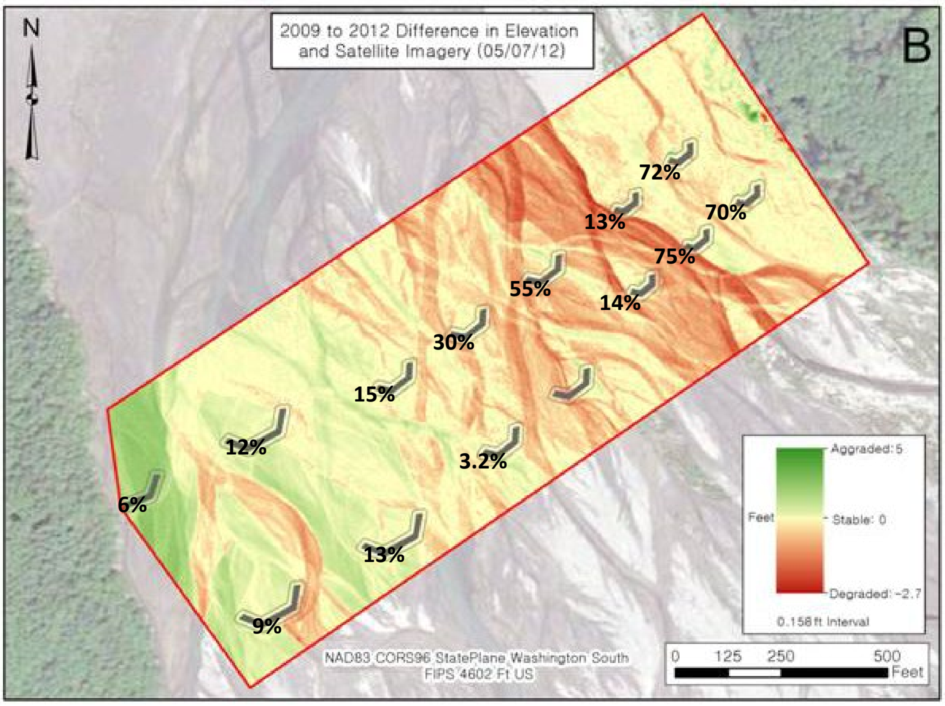
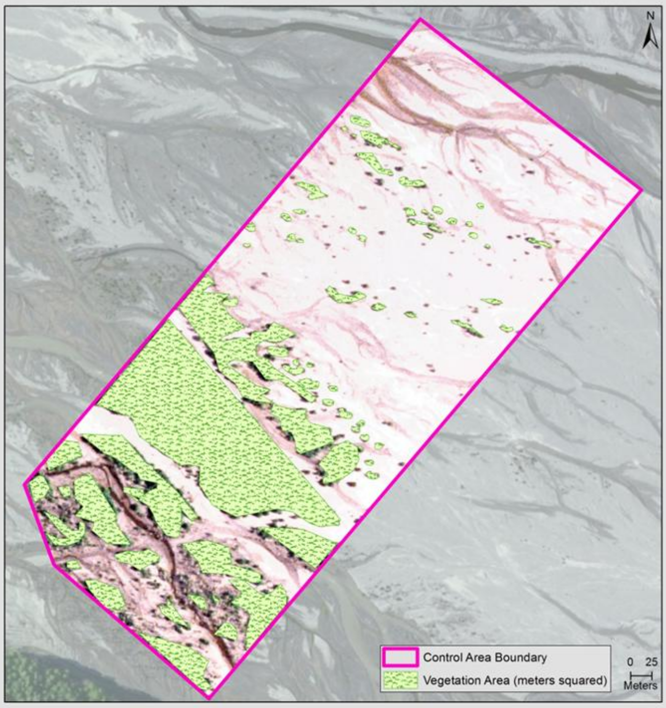


Figure 8.2 Reproduction of Figure 3.29 (b) Change map 2009 - 2012 showing the NFTR shifting north, abandoning many channels and etching into the sediment plain next to the proto-floodplain. Inserted figures indicate percentage vegetation cover at each structure.

9. Historical Survey

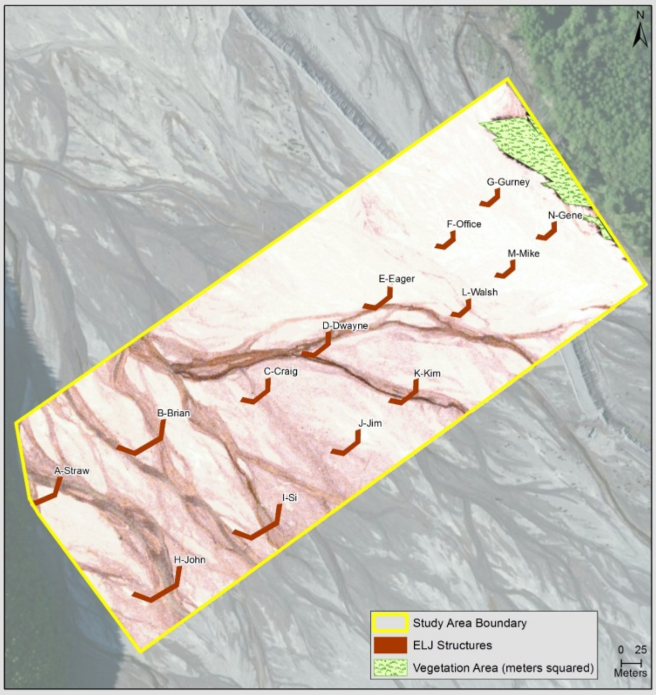
A historical survey of the ELJ and Control Study Sites was performed to better understand the fluctuating nature vegetation cover on the sediment plain and asses the performance of the ELJs in a wider context. Images of the sediment plain in 2006, 2007, 2009, 2010, 2011, and 2012 (using
19%
available imagery sourced from Google Earth and the USACE) were loaded into ArcMap and clipped to the ELJ and Control Study Sites. An orthophoto created by Josh Townsend using Structure from Motion was used for 2013 ELJ study Site, but equivalent images do not exist for the Control Site in 2013.

Vegetation maps were created for ELJ and Control Study Sites (Figs. 9.1 to 9.13) by visually identifying and then digitizing the vegetated areas in each image, using ArcMap. Once all the vegetated areas had been digitized, their areas were calculated in the attribute table by "calculating geometry" and, finally, the sum total of all the vegetated areas was calculated using the "statistics tool".



2006 Control Aerial Vegetation Estimate
62062 Meters Squared

Figure 9.1 2006 Control Site vegetation map. Total vegetated area = 62,062 m^2



2006 Study Area Aerial Vegetation Estimate
5374 Meters Squared

Figure 9.2 2006 ELJ Site vegetation map. Total vegetated area = 5,374 m^2

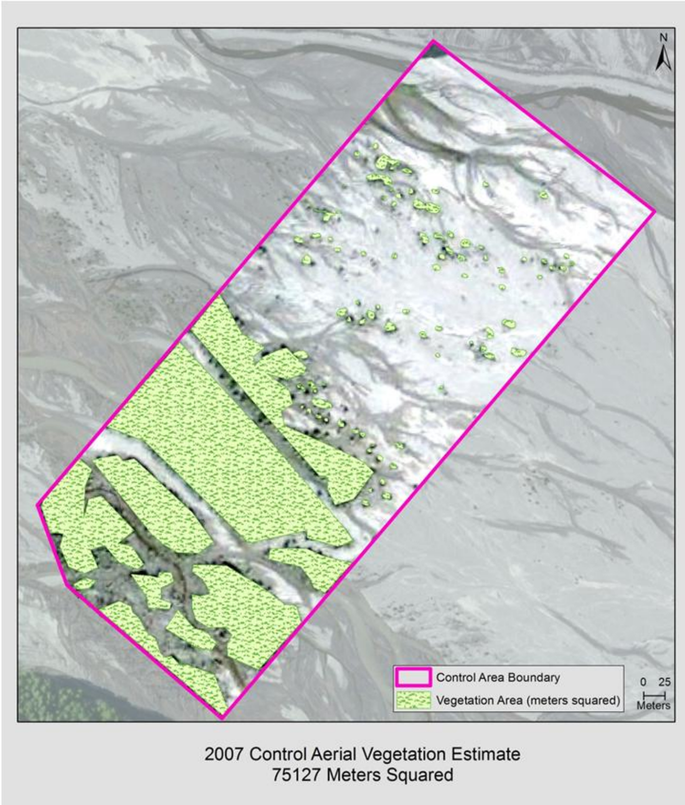


Figure 9.3 2007 Control Site vegetation map. Total vegetated area = 75,127 m^2

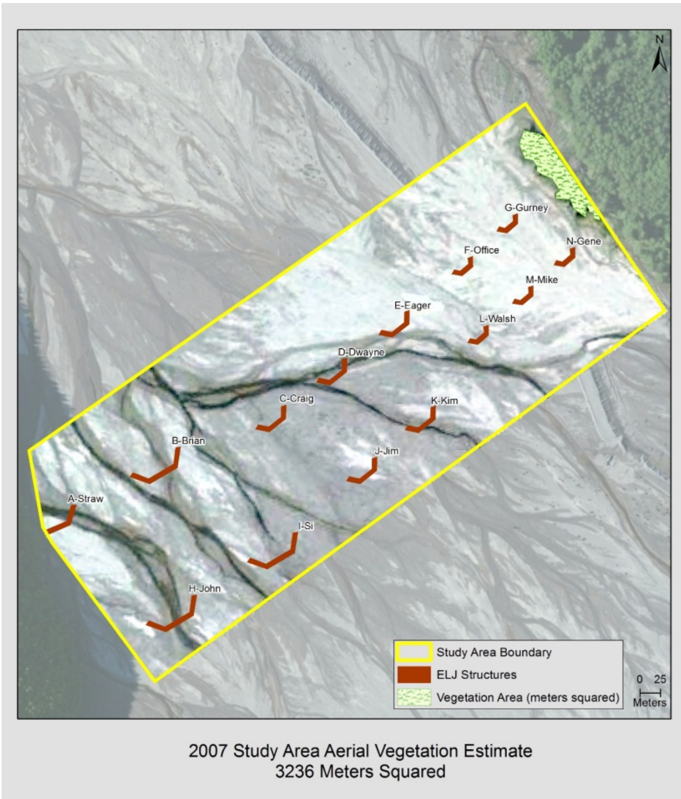


Figure 9.4 2007 ELJ Site vegetation map. Total vegetated area = 3,236 m^2

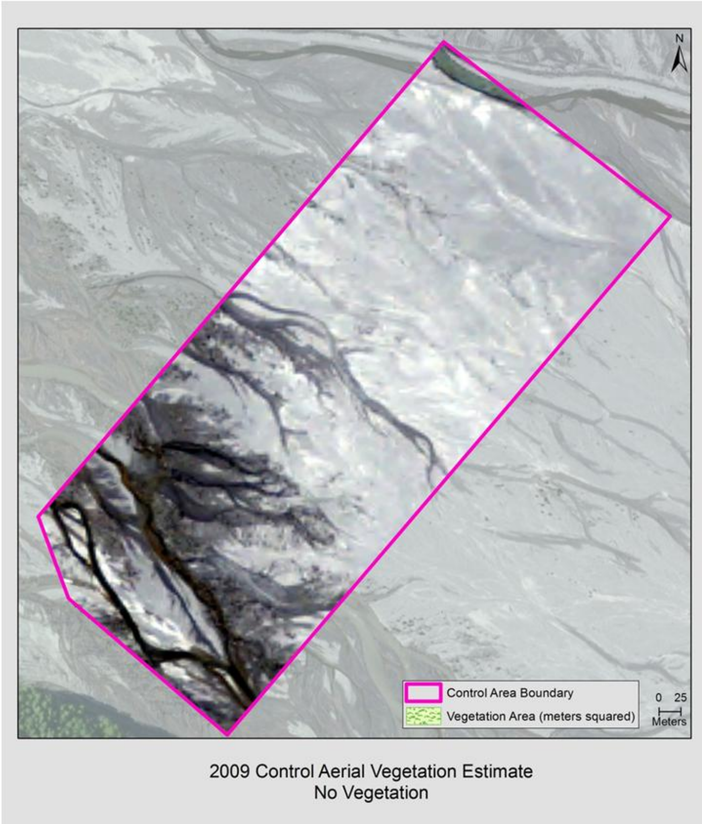


Figure 9.5 2009 Control Site vegetation map. Total vegetated area = 0 m^2

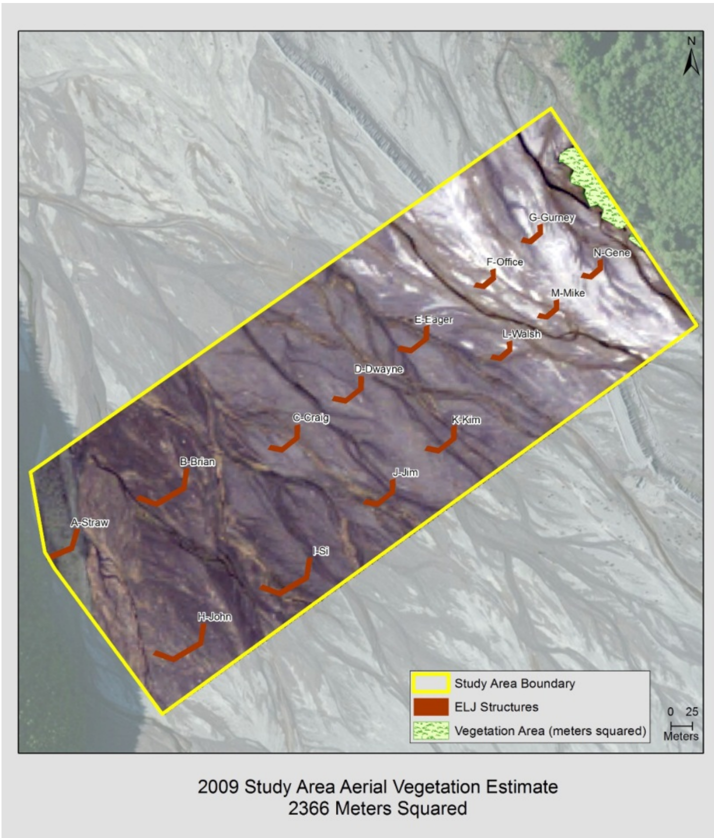


Figure 9.6 2009 ELJ Study Site vegetation map. Total vegetated area = 2,366 m^2.

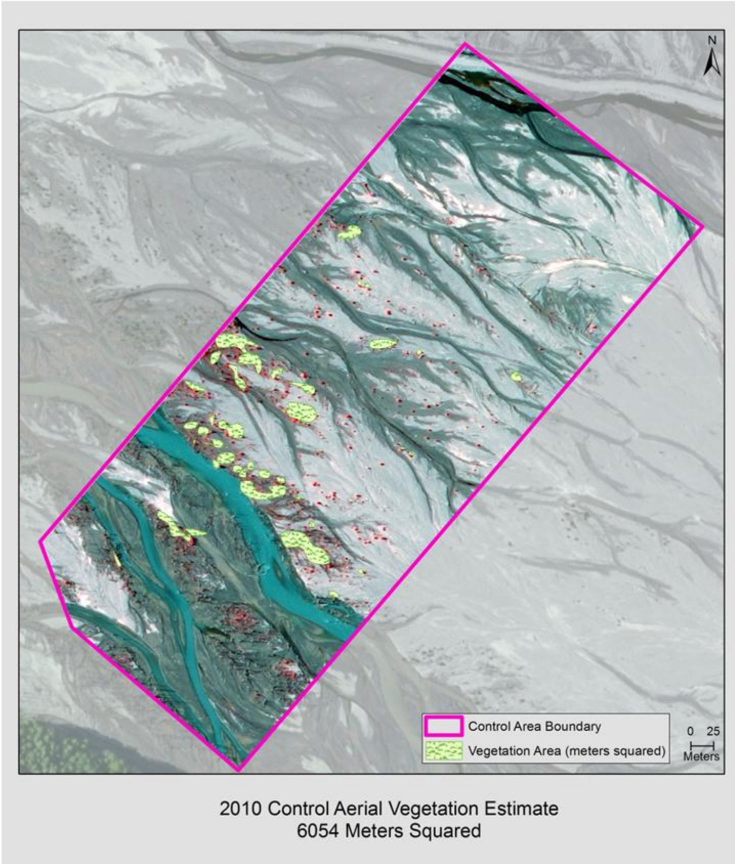


Figure 9.7 2010 Control Site vegetation map. Total vegetated area = 6,054 m^2

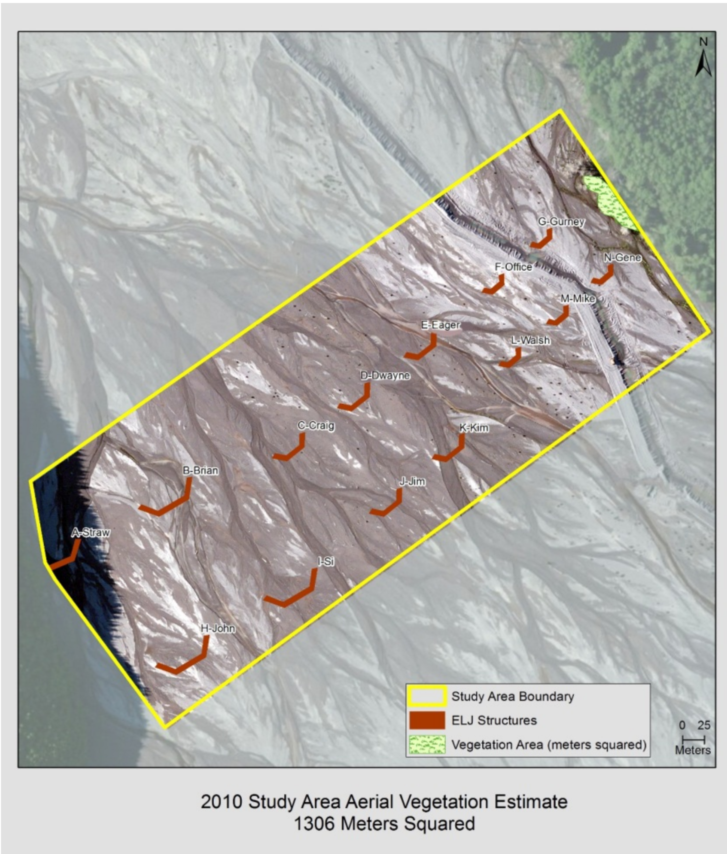


Figure 9.8 2010 ELJ Study Site vegetation map. Total vegetated area = 1,306 m^2

Figure 9.9 2011 Control Site vegetation map. Total vegetated area = 2,897 m^2

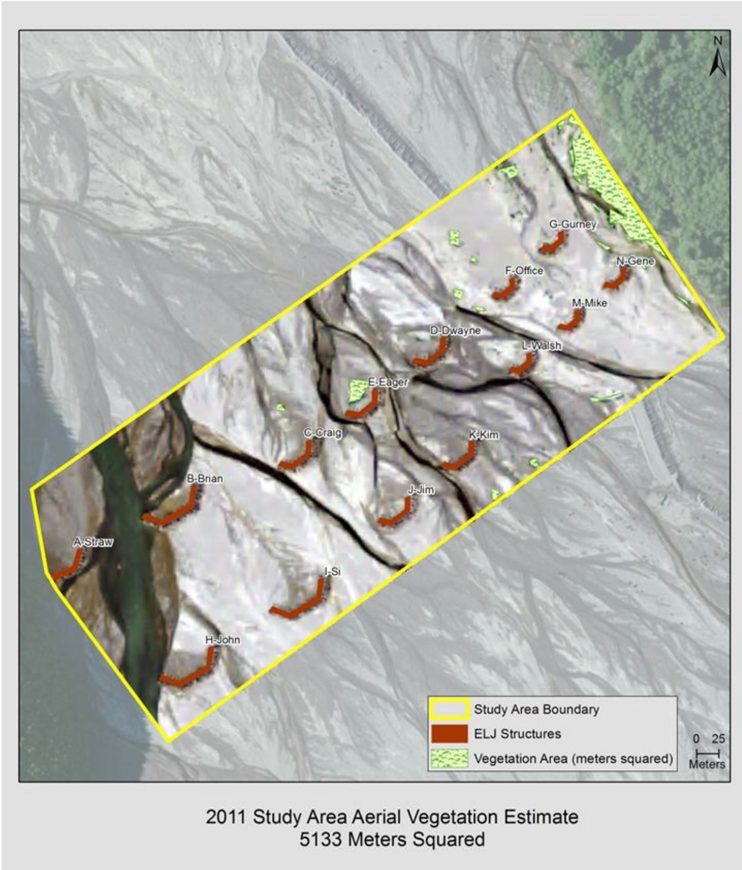


Figure 9.10 2011 ELJ Study Site vegetation map. Total vegetated area = 5,133 m^2

Figure 9.11 2012 Control Site vegetation map. Total vegetated area = 3,162 m^2

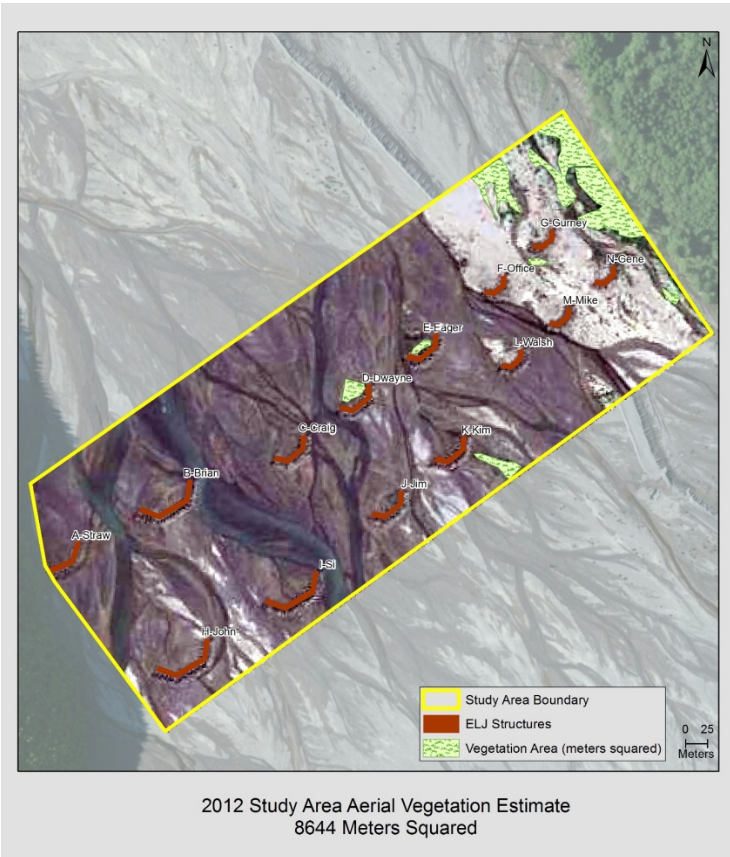


Figure 9.12 2012 ELJ Study Site vegetation map. Total vegetated area = 8,644 m^2

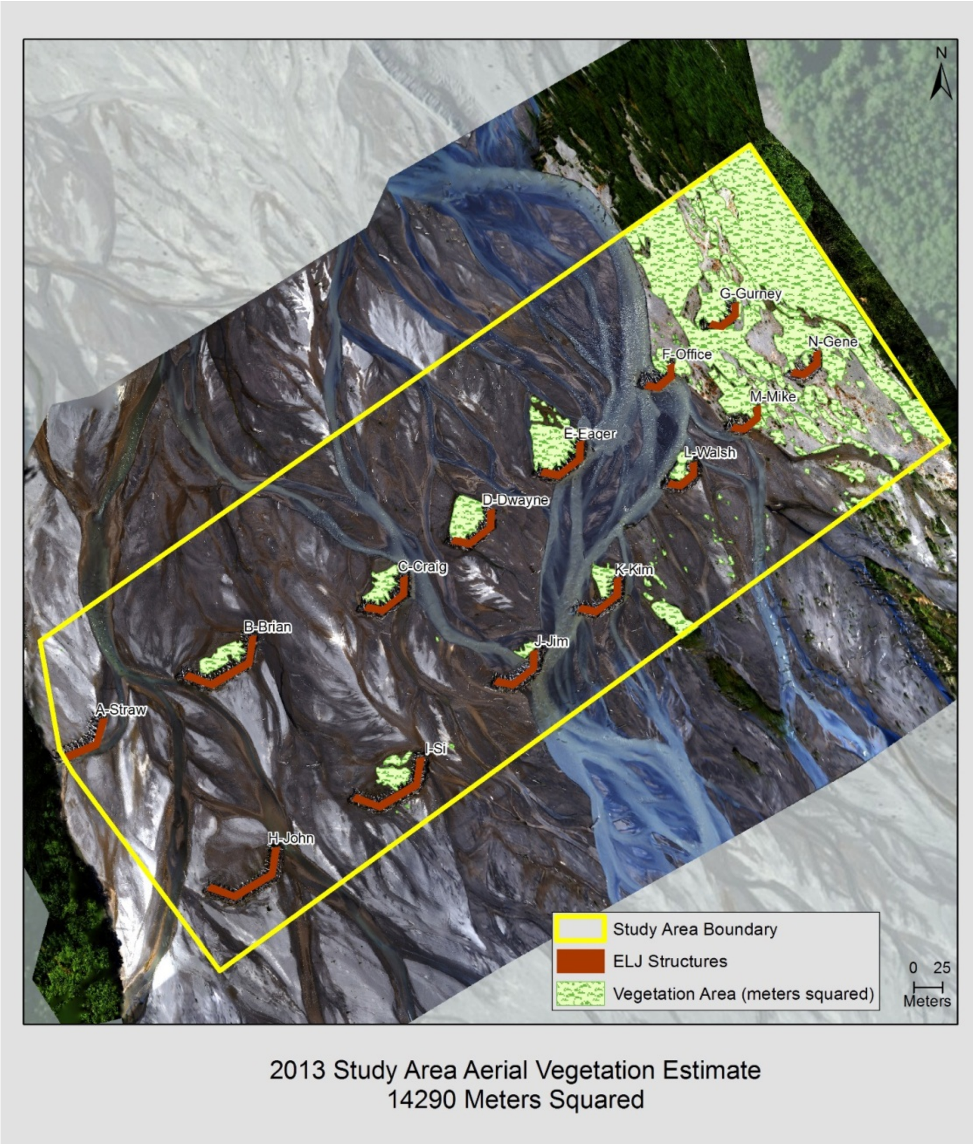


Figure 9.13 2013 ELJ Study Site vegetation map. Total vegetated area = 14,290 m^2

Table 9.1 lists vegetated areas as percentages of the 117,058 m^2 total areas of the Control and ELJ Study Sites.

Table 9.1 Historical Changes in Percentage Vegetation Cover

Year	Control Area (%)	Study Area (%)
2006	53	5
2007	64	2
2009	0	2
2010	5	1
2011	2	4
2012	3	7
2013	3*	12

ELJs constructed

*Estimate based on vegetated area data for sampled transects in the Control Site in 2013.

The dynamics of vegetation in the Control Site illustrate the extent to which vegetation can colonize the sediment plain, but it also demonstrate how quickly fluvial reworking, through channel scour and aggradation of the sediment plain can destroy even extensive areas of vegetation unless they are protected from fluctuations of the NFTR.

In contrast, the post-2010 reversal of the previous, steady decline of vegetation in the ELJ Site and its progressively accelerating spread since is encouraging, though it is impossible to attribute the pattern and increase in vegetated area entirely to the effects of the ELJs.

The percentage vegetation cover in the ELJ Study Site as a whole in 2013 (estimated from the orthophoto shown in Figure 9.13 and listed in Table 9.1) is substantially lower than those calculated for the areas protected by the ELJs (based on the transects behind the structures). This is also encouraging as it indicates that the areas behind and, hence, protected to a greater or lesser degree by, the ELJs are not only more extensively vegetated than the equivalent areas in the Control Site, but also much better vegetated than the remaining, unprotected area of the sediment plain in the ELJ Study Site.

10. Conclusions

The aim of the biotic study was to evaluate the vegetative response to the installation of the 14 ELJs on the Sediment Plain and characterize the plant species composition there. It was recognised that achieving this aim would also require knowledge of the historical development and evolution of vegetation on the sediment plain in the AoI. The research questions posed at the outset of the biotic study were:

1. What are the plant species compositions within the ELJ and Control Study Sites?
2. Do plant assemblages remain the same/similar across the sediment plain?
3. What are the percent vegetation cover, species abundance, and species diversity values at each ELJ?
4. Does the proximity of an active sub-channel of the NFTR affect vegetation percentage cover?
5. Is the vegetation on islands in the ELJ Study Site successfully trapping and retaining sediment, storing sand, and building grade?
6. Does distance from the valley side impact vegetation percentage cover?
7. Does the presence of grass species have any impact on presence of woody species?
8. Does the presence of leguminous species impact percentage cover?
9. Has vegetation cover increased since installation of the ELJ structures?

Each of these questions is addressed in these conclusions.

Q1. What are the plant species compositions within the ELJ and Control Study Sites?

The Sediment Plain of the North Fork Toutle River upstream of the SRS is the product of dynamic fluvial processes that are dominated by aggradation and that is constantly being reshaped by sediment deposition, re-entrainment and reworking. It is a highly disturbed environment and the plants and plant communities on it reflect this.

Vegetation on the sediment plain is dominated by pioneer species that are adapted to colonize and survive in recently disturbed environments where nutrient availability is limited. *Alnus rubra* (Red Alder) is the by far dominant species, able to occupy the sediment plain despite its coarse, nutrient poor sediments through its microbial symbiosis with *Frankia actinomycetes* which enables it to fix nitrogen from the atmosphere. Similarly, leguminous species including *Lotus corniculatus (*Birdsfoot Trefoil*)* and *Lotus micranthus* (Small-flowered Lotus) have a considerable advantage over other forb species due to their ability to fix nitrogen.

Phalaris arundinacea (Reed Canary Grass) has excluded other plant species in some areas by creating thick, monotypic patches scattered across the sediment plain. This is typical for this highly invasive non-native species, which is known to invade and dominate disturbed wetlands/wet habitats throughout the Pacific Northwest (Tu, 2004).

Wetland indicator species, primarily plants from the *Juncus* genus are found across the sediment plain, and they dominate in the lower, wetter areas close to the main anabranches of the NFTR. *Juncus bufonius* (Toad Rush) is the wetland indicator species found most widely on the sediment plain, which is to be expected as it has previously been documented to dominate wetlands during early succession on and around Mount St. Helens (Dale, 2005). In addition to these species, other disturbance-following, often non-native, forbs are scattered throughout the sediment plain. Vegetation found in the study areas can be put in to 5 main categories: early succession herbs, grasses/upland sedges, wetland species, nitrogen-fixing legumes, and trees; with the majority of species producing light seeds that rely on wind for seed dispersal (Dale, 2005).

Q2. Do plant assemblages remain the same/similar across the sediment plain?

The NMDS ordinations and cluster analysis give visual confirmation that plant composition remains broadly similar across sediment plain with the dominant species falling into five main categories: early-successional herbs, grasses/upland senses, wetland species, nitrogen-fixing legumes, and trees (Dale, 2005). There is slight heterogeneity in that obligate wetland species are entirely absent in the northern third of the sediment plain where facultative and upland species are favoured. This area is higher and drier because it comprises a proto-floodplain that has not been disturbed by the NFTR for at least five years and which receives clear water runoff from Hoffstadt Creek, Valley Side Springs and exfiltrating ground water. This trend reflects the drier conditions encountered in the northern third of the sediment plain but could also indicate that obligate wetland species, primarily from the *Juncus* genus, cope better than other plant varieties with disturbance and burial associated with frequent reworking and aggradation of the plain in the vicinity of the main sub-channels of the NFTR located in the southern two thirds of the sediment plain. Conversely *Cytisus scoparius* (Scotch Broom), a non-native shrub known to be highly invasive is found in dense patches in the Control Site but is largely absent from the ELJ Study Site. The reason for this is not readily apparent and cannot be attributed to the presence of the ELJs.

Q3. What are the percent vegetation cover, species abundance, and species diversity values at each ELJ?

The transect surveys were successful in providing for each ELJ quantitative data defining the percentage of the area behind the structure covered by vegetation, species abundance and species diversity. Surveys in the Control Site (an area identical in dimensions and shape to the ELJ Study Site but located just upstream within the Area of Interest) and conducted along transects located at points equivalent to those of the island building structures in the ELJ Study Site, allowed quantitative data for the same vegetation parameters to be derived for an area unaffected by the ELJs. The relevant results are listed and displayed in Sections 5 and 6.

Q4. Does stream channel presence impact vegetation percent cover?

Correlation analysis revealed a moderate, negative relationship between the number of active sub-channels present in the influence area of each ELJ and percentage vegetation cover. This indicates that as the number of active sub-channel in and around a structure increases, vegetation cover decreases. Although the relationship is not strong and does not prove causality it is consistent with the idea that active channels that rework sediment deposited behind the island/grade building structures both limit the initial establishment of vegetation and destroy previously established vegetation through re-entraining deposited sediment.

5. Is vegetation successfully holding sediment and creating aggradation?

The 2013 and historical surveys indicate that the island/grade building structures have encouraged vegetative colonisation of the sediment in the ELJ Study Site by a variety of wetland, facultative and upland species. It is also clear that these species can spread and flourish despite the nutrient poor environment and that they are untroubled by channels in the northern third of the sediment plain that convey clear water runoff from Hoffstadt Creek, Valley Side Springs and exfiltrating ground water. It also appears that the structures and vegetation can cope with the smaller sub-channels of the NFTR. When considered alongside data on elevation changes in the sediment plain between 2009 and 2012, the answer to Question 5 is, therefore in the affirmative.

That said, there is ample evidence that vegetation growing behind the island/grade building structures is currently unable to withstand attack by the larger anabranches of the NFTR and entirely unable to withstand the mainstem itself. Not only are the roots of the pioneer species insufficiently deep and dense to bind the loose sediment in which they are growing but also several of the ELJs no longer provide sufficient protection, having lost their racking. Additionally, NFTR anabranches are able to pass between the structures, make sharp turns and attack the islands and proto-floodplain behind the ELJs at surprisingly oblique angles and the pockets between the wings are insufficiently deep to offer protection from such flank attacks. Destruction of what was in 2012 an extensive, vegetated island behind Walsh and serious erosion of the wooded, proto-floodplain behind Office are clear examples of this unexpected fluvial phenomenon.

6. Does proximity to valley edge impact vegetation percent cover?

There is a moderate, negative relationship between distance from the nearest valley side and percentage vegetation cover, indicating that vegetation cover decreases towards the center of the sediment plain. This might have more to do with channel activity than with proximity to edge as previous studies in the Mount St. Helen's area have found that seed abundance nor plant density correlates with absolute distance to a seed source (Dale, 1989).

7. Does the presence of grass species have any impact on presence of woody species?

Based on the literature, it would be expected that the presence of *Phalaris arundinacea* (Reed Canary Grass) as the dominate grass species on the sediment plain*,* should adversely impact the potential for other plants, including tree species, to colonize the area. In fact, correlation analysis revealed a statistically significant, positive relationship between the abundances of the dominant tree species, *Alnus rubra*, and *Phalaris arundinacea*. This indicates that these two species are able to co-exist in same areas and that *Phalaris arundinacea* is not be having a significant impact on the establishment of *Alnus rubra* at this time. It may be the case that as the canopy created by *Alnus rubra* expands, these trees will successfully shade out the grasses. In the case of *Phalaris arundinacea* this would be desirable as it is an invasive, non-native species.

8. Does the presence of leguminous species impact percent cover?

All of dominant leguminous plant species found on the sediment share a strong positive relationship with percentage vegetation cover. This not only indicates that leguminous species have an advantage over other plant types, but suggests that they also aid non-leguminous plant species in becoming established on the sediment plain. In addition to their ability to fix nitrogen, leguminous forbs including lupine have been found to physically trap windblown debris and attract insects, many of which ultimately die on or around the plant enriching the soul as they decompose. Studies on Mount St. Helens have found that soils under lupines have much higher total nitrogen, organic material, and microbial activity than adjacent bare areas (Dale, 2005). A similar process is likely taking place on the NFTR sediment plain.

9. Has vegetation cover increased since the installation of the ELJ structures?

It is clear from the contemporary and historical Control vs ELJ Study Site surveys that the ELJs have been successful in accelerating colonization and establishment of vegetation. Also non-native, invasive species, mainly, *Cytisus scoparius*, appear to be less prevalent in the ELJ Study Site than the Control Site. The main concern is that clear gains made since 2010 are about to be jeopardized by the deteriorating condition of racking on several of the structures, coupled with imminent, flanking attack by the NFTR mainstream anabranches of the smaller Type-A structures protecting the densely wooded, proto-floodplain in the northern third of the sediment plain in the ELJ Study Site.

11. Interpretation & Recommendations

A better understanding of the plants and plant communities colonizing the sediment plain in the ELJ and Control Study Sites should help inform how the USACE manages the ecosystem in order to promote improved habitat development. Based on experience and observations gained in the Biotic Study of the sediment plain it would, however, be premature to begin a planting campaign until more is known about soil and microbial conditions in the sediment plain.

Currently, the level of protection several of the ELJs offer for vegetation is insufficient and the time that has elapsed since the structures were installed is insufficient for the vegetation to be able to withstand attack by the main river or its larger anabranches. The main issue is that the racking installed in 2010 has not been replaced by large woody debris carried from upstream sources by the NFTR and deposited against the ELJs. This is the case because the supply of LWD from the catchment is still far below what would be expected in an upland river in the Cascades because trees in the upper NFTR watershed have yet to recover from decimation during the 1981 eruption (Franklin, 1990). At the moment, the time between disturbance events is just too short to allow plant communities behind the structures to reach the age/size/strength at which they can withstand scour by the NFTR.

Maintenance should include re-racking ELJs as necessary, coupled with the addition of large wood debris, or possibly permeable planking, and planting live stakes and saplings within the structures to help stabilise naturally established vegetation.

If the Portland District USACE does pursue planting in the future they may not necessarily need to mimic the plant communities sampled on the sediment plain, but whatever plant species and assemblages that are used should be designed to function in ways similar to those species demonstrated in this study to be able to colonize the sediment plain successfully.

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Appendix A: Corps Brochure

Grade Building Structures

The U.S. Army Corps of Engineers will construct a series of structures in the Mount St. Helens sediment plain above the Sediment Retention Structure. These structures are part of a pilot study to find new ways to manage the sediment still being released into the North Fork Toutle and Cowlitz river systems.

From July through October 2010, the Corps' contractor, LKE Corporation, will build a series of island forming structures and a diversion berm designed to slow down the river's flow, allowing sediment to settle before it gets into the watershed.

The Corps will monitor sediment activity to evaluate the potential long-term role of the structures in reducing flood risks to the communities along the lower Cowlitz River. The project is funded through the American Recovery and Reinvestment Act of 2009.

Access to the sediment plain is limited and the construction zone is restricted. Visitors to the area can see the construction activity from viewing areas at the Sediment Retention Structure and at the Hoffstadt Bluffs Visitor Center .

Please comply with all construction signs and personnel.

US Army Corps of Engineers®
Portland District

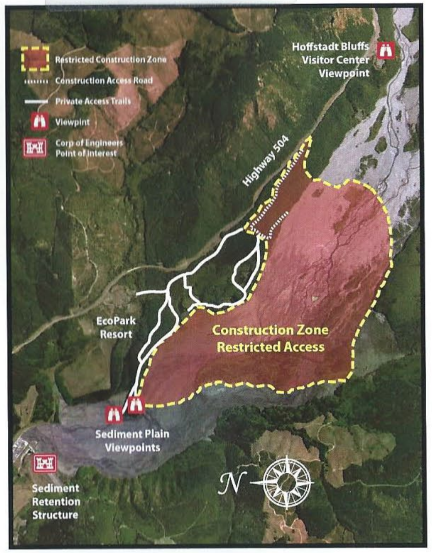
If you have any questions regarding the construction project or access restrictions, please contact either

Tim Kuhn, Project Manager
503.808.4752
tim.s.kuhn@usace.army.mil

or

Marci Johnson, Project Coordinator
503.808.4765
marci.e.johnson@usace.army.mil

Web: http://www.nwp.usace.army.mil



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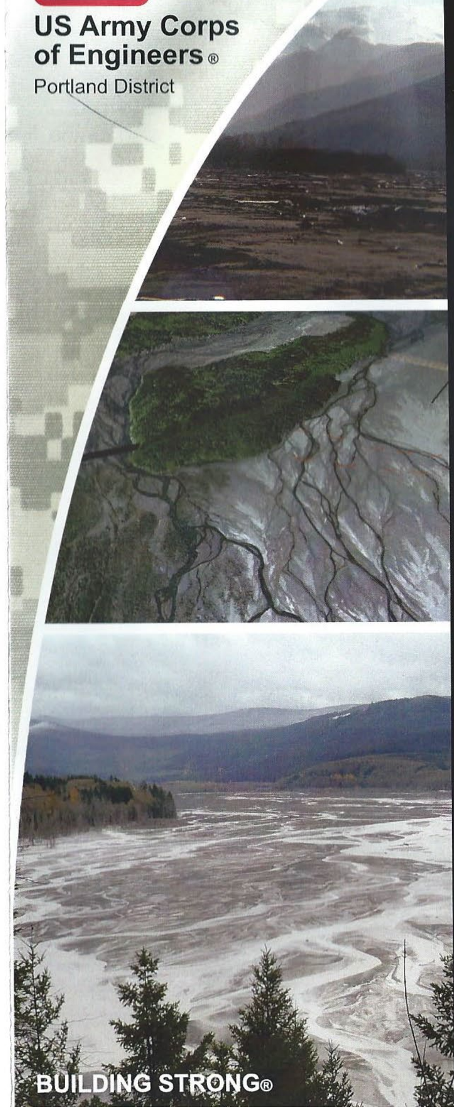


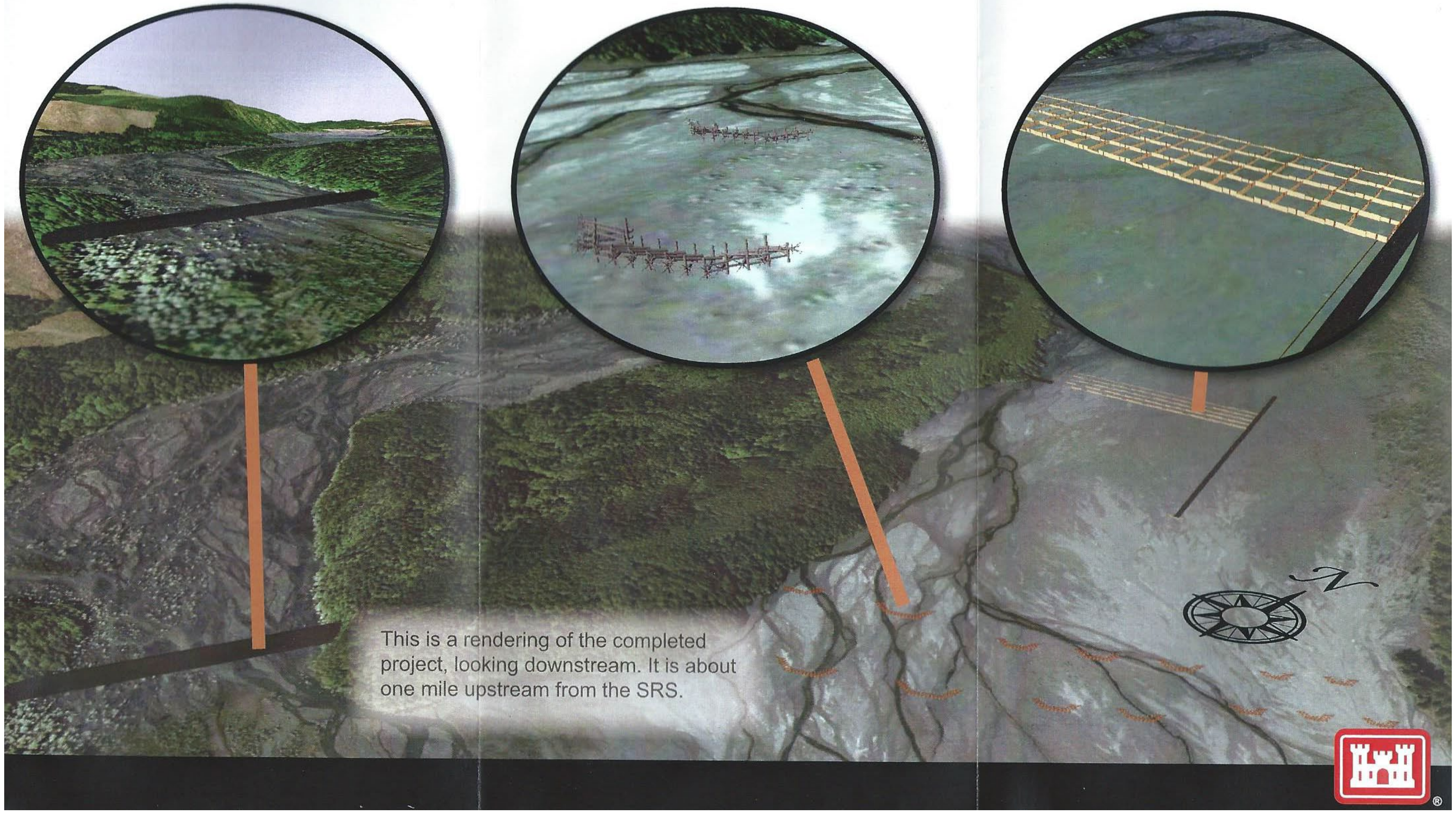
Mount Saint Helens Grade Building Structures Pilot Project

The goal of the pilot project is to test the effectiveness of the wooden grade building structures constructed on the sediment plain to trap sediment coming off the mountain. The pilot project consists of:

The diversion berm will direct the majority of flow over the structures in the test area for the duration of the monitoring period.

A series of “engineered log jams” will produce an eddying effect as water flows around them, causing sediment to drop out in the slower water, creating islands behind each log jam.

A “step-weir and baffle” system is a series of posts and panels which slow down the river, causing a pool to form during high-flow events; this allows sediment in the water to settle upstream, inside the structure.



This is a rendering of the completed project, looking downstream. It is about one mile upstream from the SRS.

Appendix B: Copy of Successful Proposal

Geomorphic and Ecological Assessment and Evaluation of Grade Building Structures on the SRS Sediment Plain, North Fork Toutle River

Project Overview

The project will assess, evaluate and visualise the morphological, sediment and ecological performance of thirteen large Engineered Log Jam (ELJ) structures designed to promote grade building and create habitat on the sediment plain upstream of the Sediment Retention Structure on the North Fork Toutle River.

The project will begin by making use of data obtained from historical remote sensing and on-site surveys. The information obtained from these existing sources will be supplemented by new measurements and observations made at the site by the project team to support advanced geomorphic, sediment and ecological investigation and visualisation of: channel evolution; bar dynamics; adjustments to surface sediment grain sizes; changes in vegetation assemblages, and; ecosystem recovery (aquatic, amphibious, terrestrial and avian). The aim is to establish, understand and explain how the fluvial, sediment and eco-systems have responded to installation of the structures. This will allow the team to evaluate the practical utility of the structures and their benefits to date in terms of sediment management and environmental mitigation.

Fieldwork would also include a condition assessment of each of the structures, leading to recommendations for a long-term programme of monitoring, maintenance and adaptive management to ensure that they continue to function effectively.

Finally, the project would assess the morphology and fluvial dynamics of Alder Creek, which confluences with the North Fork Toutle River in the vicinity of the ELJs. Concerns have been expressed concerning the implications of raising the spillway of the SRS for accelerated sedimentation in the lower course of Alder Creek, with adverse impacts for fish passage between the creek and the NFTR. In this regard, the possibility of installing additional ELJs to control sedimentation in the vicinity of the confluence in order to maintain flow connectivity and fish access to Alder Creek. The results of this geomorphic assessment would be presented and discussed with USACE Portland District staff in order to evaluate the potential for using additional ELJs and the feasibility of this approach to keeping Alder Creek connected to the NFTR.

While the results of this project would be of immediate use to the USACE in evaluating the performance of the Grade Building Structures, their potential for use in environmental/ecological mitigation, and the feasibility of installing additional ELJs to protect Alder Creek they would also have wider significance and utility in the context of use of ELJs in the Pacific North West more generally.

It is envisaged that the project would lead to multiple conference presentations and potentially one or more journal publications, co-authored by the researchers together with staff from the Portland District, US Army Corps of Engineers.

Scope of Work

The project team will document and explain fluvial processes, morphological changes and ecological responses to the Grade Building Structures constructed on sediment plain in the NFTR. Specifically, the team will investigate, characterise and account for pre- and post-construction patterns and trends of dynamic adjustment in:

1. Channels
2. Bars
3. Vegetation assemblages
4. Bed material grain sizes
5. Aquatic, amphibious, terrestrial and avian species

The team will also undertake detailed surveys of each structure and compare these against its ‘as built’ condition to support:

6. Condition assessment, and
7. Suggest a programme of monitoring, maintenance and adaptive management that would ensure that the structures continue to function effectively and as intended.

In parallel, the PI will assess the morphology and fluvial dynamics of the lower reach of Alder Creek and its confluence with the North Fork Toutle River, with a view to evaluating:

8. Potential for using additional ELJs to keep Alder Creek connected to the NFTR as the effect of raising the spillway of the SRS drives further aggradation of the sediment plain.

Time Line

The project will begin in January and end in September 2013. Key dates and activities are:

January	Project Initiation.
February	Principal Investigator arrives in Portland and begins compilation of original design drawings/criteria, existing data and information.
Mar-May	Analysis and evaluation of existing data and information coupled with preliminary site visits and studies (depending on weather, flows and accessibility of site). Over flights to observe detailed flow patterns at a variety of discharges (also subject to weather).
June-July	Drafting of interim report on performance of structures to date and site surveys to collect primary data/information on current condition of channels, bars, vegetation and structures.
August	Development and testing of visualisation and communication software for knowledge transfer to end users, stakeholders and other interested parties.
September	Delivery of (a) Final Report and (b) Visualisation and Knowledge Transfer Package. End of Project.

Deliverables

The outputs to be delivered to the sponsor are:

(1) <u>A Site Reconnaissance Report</u>

In three hard copies plus one electronic copy (format : Adobe.pdf), with drawings half size prints, on 11 by 17 inch paper. The draft report will also be placed in DrChecks for review. This deliverable will consist of two components:

a) Draft Report and,
b) Field Notebook.

(2) <u>Final Report</u>

In three hard copies and one electronic copy (format: Adobe.pdf), with drawings half size prints, on 11 by 17 inch paper. The Final Report will consist of 5 components:

a. Final Report
b. Annex I: Plates and Figures
c. Annex II: Notebooks
d. Annex III: Data archive (including all measurements, results and meta-data .

Task Order Management

The team will supply via e-mail (format: Adobe .pdf):

a. Project Work Plan
b. Project Quality Control Plan

Contract Administration and Accounting

The Contractor will submit the documents necessary to support contract administration and accounting, including:

a. Monthly Invoices on ENG 93
b. Monthly Progress Reports
c. Monthly Expenditure Reports (as necessary)
d. Monthly Safety Exposure Report (Person-hours)
e. Final Invoice and Release of Claims

Staffing

Dr Colin Thorne	Principal Investigator responsible for geomorphic assessment and evaluation, and delivery of the project outcomes indicated in SoW.
Dr Gary Priestnall	Remote Sensing, Data Analysis and Visualisation Specialist
MSc student 1 (UK)	To assist with processing remote sensing data, GIS, fieldwork and visualisation of results for effective communication with stakeholders.
MS student 2 (USA)	To assist with quadrate surveys, biogeography and ecological interpretations.

Performance Schedule

TASK	**MILESTONE (Calendar Days after NTP)**
Notice to Proceed	-
Work Plan and Site Reconnaissance Plan	24 (10%)
Site Reconnaissance Report	180 (40%)
Government Review Comments Provided	190
Draft Report Submittal	200 (90%)
Government Review Comments Provided	210
Final Report Submittal	230
Task Order Completion Date	240 (30 Sep 2013) 100%

Dates for milestones specified in the Table above may be change through negotiation during progress review meetings without a modification to the task order. However, any changes to the scheduled completion date for the project would require modification to the task order. If notice to proceed is received at the beginning of February, all services performed under the task order will be completed by 30 September 2013.

Appendix C: Over-arching Conclusions and Recommendations

1. This project has successfully assessed, evaluated and visualised the morphological, sediment and ecological performance of the fourteen large Engineered Log Jam (ELJ) structures designed to promote island formation and grade building on the sediment plain approximately 2 miles upstream of the Sediment Retention Structure (SRS) on the North Fork Toutle River (NFTR). The results indicate that the ELJs have performed well with respect to deflecting flow and generating eddies, inducing deposition and forming islands. However, three years after construction, response of the NFTR and the channels of other, smaller watercourses is not yet complete and the islands and proto-floodplains formed downstream of the ELJs are still evolving. Hence, further shifting and evolution of the channel pattern is expected and changes in the islands and proto-floodplains are inevitable.
   It is recommended that monitoring of channel changes in the NFTR and other streams crossing the sediment plain in the Area of Interest (AoI) and repeated appraisal of the functionality of the ELJs continues for at least a further three years.
2. Repeat sampling of surface sediments upstream, within and downstream of the ELJs indicated that size distributions and downstream trends were similar to those found in the 2009 and 2010 surveys. While it is clear that the Pilot Project as a whole has trapped a lot of sand, it is not possible to establish to what extent the ELJs contributed to the project's trapping efficiency.
   It is recommended that surface sediments be resampled, perhaps in 2 years to establish whether additional sand is being trapped and retained by the Pilot Project. Repeat LiDAR should be continued and used to establish changes in the volume of sediment stored upstream of the Diversion Berm, CVS and in the ELJ Study Site.
3. The ELJs were built to specification, their current structural integrity is excellent and the posts and logs seem invulnerable to attack by the NFTR. However, many structures have lost much or all of their racking and the berms of several structures are damaged. The results of the abiotic study demonstrate that the islands and proto-floodplains of ELJs with missing racking and/or damaged berms are vulnerable to disturbance and reworking by the NFTR. The results of the Biotic Study show that vegetation is less extensive and diverse downstream from the affected ELJs. After three years exposure to the harsh environment of the sediment plain, the racking on all the ELJs is brittle and buoyant and it is likely that unless maintenance is performed, the functionality of the structures will deteriorate further in the near future. Lack of racking was responsible for the condition of two ELJs being unacceptable and dysfunctional and a further five being unsatisfactory and only partially function.
   Bearing in mind the excellent structural integrity of the ELJs, it is recommended that maintenance be performed to replace lost/ineffective racking and reconstruct damaged berms as necessary to restore their functionality to 'As built' status. This might best be achieved through re-racking coupled with the addition of large woody debris, or possibly permeable planking, and planting

live stakes and saplings within the structures to help stabilise naturally established vegetation. Further maintenance might be necessary in a few years and this should be checked as part of the monitoring of the pilot project that was specified in the original Corps brochure (Appendix B).

4. There is no evidence that sediment loads in the North Fork Toutle River (NFTR) elevated by the 1980 eruption of Mount St Helens are likely to return to pre-eruption levels in the foreseeable future.
   It is recommended that research and pilot projects on new and innovative ways to trap and retain more sediment (especially sand) upstream of the SRS should continue. These should include continued studies of the utility of wood structures and vegetation planting on the sediment plain in conjunction with further spillway raises and other measures.
5. The 2012 spillway raise, together with subsequent raises planned for the future, should allow the SRS to store an additional 44 mcy of sediment. However, there is a risk that continued aggradation around the mouths of tributaries including Alder, Deer and Hoffstadt Creeks might disconnect them from the NFTR. This is significant because these creeks drain watersheds unaffected by the 1980 eruption and which support ESA-listed Chinook Salmon *(Oncorhynchus tshawytscha)* and Steelhead Trout *(Oncorhynchus mykiss)*.
   It is recommended that consideration be given to constructing additional wood structures, possibly including ELJs, to reduce aggradation rates around tributary junctions so that connectivity to the NFTR, and thus fish passage, can be maintained.
6. The current review of the trap and haul program for salmonids has renewed interest in the possibility of improved provision for natural (i.e. volitional) fish passage downstream, and perhaps upstream, through the SRS spillway and across the sediment plain, from and to these tributaries. The results of this study of wood structures constructed in the 2010 Pilot Project and the spread of vegetation in areas protected by the ELJs suggest there is merit in this proposal.
   It is recommended that further research be performed to develop designs for wood structures and planting schemes that could be used to reduce (but not eliminate) rates of aggradation around tributary mouths, perhaps involving physical modelling and a prototype-scale pilot project to establish the feasibility of this approach.
7. The results of the Abiotic Study reveal that a local drainage system is developing on the proto-floodplain that has developed in the northern third of the sediment plain between Hoffstadt Bluffs and the ELJs. This is conveys clear water sourced from Hoffstadt Creek, seepage from springs along the valley side or exfiltration of groundwater beneath the sediment plain. This clear water often occupies a wall-base channel located between the northern edge of the sediment plain and the valley side. A similar wall base channel runs along the southern edge of the sediment plain, between the tributary mouths of Deer and Alder Creeks. The southern wall-base channel may be traced all the way downstream from Alder Creek to the SRS spillway.
   It is recommended that consideration be given to enhancing these wall base channels, which are known to provide good habitats (especially rearing) and pathways for anadromous fish and which could have a beneficial role in promoting volitional passage across the sediment plain.
8. The results of the Biotic Study demonstrate that pioneering species, especially alder and leguminous species that fix nitrogen, can rapidly colonise the sediment plain. The variety of plants on the sediment plain is limited, but the extent, richness and diversity of vegetation on islands and proto-floodplains downstream of the ELJs far exceed the equivalent parameters in

the Control Site, demonstrating the success of the ELJs in promoting revegetation of the sediment plain.

9. Spatial variability in the plants sampled in the Biotic Study suggests that obligate wetland species dominate in the lower, wetter southern half of the sediment plain, while facultative and upland species dominate in the northern half. The study further reveals that invasive, non-native plants such as Scotch Broom that are present in the Control Site are absent in the ELJ Study Site. It is not, however, possible to attribute these differences directly to the impacts of the ELJs.
   It is recommended that further investigations of vegetation on the sediment plain be performed to develop causal links between the impacts of the ELJs, vegetation types and plant assemblages.
10. Evidence emerging from channel resurveys in the lower Cowlitz hints that the progressive siltation experienced until recently has been reversed – perhaps in response to the Pilot Project and no doubt promoted by the 2012 spillway raise. However, the results are equivocal and this reversal is far from proven.
   It is recommended that a carefully designed program of monitoring, analysis and performance appraisal be performed to establish causal links between the Pilot Project, spillway raise and siltation in the lower Cowlitz and so judge the success of these works. This would be both sensible and consistent with the aim, stated in the 2010 Corps' Brochure, to "evaluate the potential long-term role of these structures in reducing flood risks to communities along the lower Cowlitz River".

Appendix D: Condition Survey Summary Produced by Dr. Colin Thorne

Structure	Condition	Functionality	Recommendation
Str**A**w	Unsatisfactory	Partial	Urgent - Repair

Str**A**w is in surprisingly good condition considering that it took the full force of the NFTR once the river was returned to a course to the North of the big island, in October 2010. Practically all the racking is gone, though some drift wood has lodged against the piles and some vegetation has started to grow. The sediment surface behind the structure is noticeably higher than that in the channel that flows around the right wing. This is likely due to the effect of the cross-valley structure downstream, which deflects the NFTR to the right and away from Str**A**w. It is also apparent that the small sub-channel of the NFTR that currently encounters the structure has probably incised by 1 or 2 feet since 2010. In any case, the elevation difference between the attached bar (island?) downstream of Str**A**w and the adjacent channel may be partially attributed to the past functioning of the structure. It is, however, unclear whether it would continue to function as intended should the main channel of the NFTR return to attack it again, though this does not seem an imminent prospect as the NFTR is current over at the right side of the sediment plain, interacting with the Type A structures. Nevertheless, urgent repairs are needed as the NFTR could change course again at any time.

Figure 5.4 Condition Assessment for Structure A - Str**A**w.

Structure	Condition	Functionality	Maintenance Requirement
Brian	Unsatisfactory	Partial	Urgent - Repair

Brian is structurally sound although it does not appear to have been built with a berm. There was heavy attack by the mainstream NFTR in 2011, with flow through the left wing removing racking and cutting across the island from left to right at an obtuse angle (similar to what is currently happening at Wa**L**sh), The island was dissected and seriously eroded in 2011, though the cross-island channel was filled-in by deposition in 2012, as the NFTR mainstream migrated to the north and east. Nevertheless, this reworking of the island has made its current vegetated area very small and triangular. The structure was heavily attacked by the mainstream NFTR in 2011, so it is doing surprisingly well in light of that. However, racking is missing entirely from the left wing and vegetation (grass) is limited in extent, sparse in density and of low diversity.

Figure 5.5 Condition Assessment for Structure B - **B**rian.

Structure	Condition	Functionality	Maintenance Requirement
Craig	Acceptable	Adequate	Maintain & Report

Craig is in generally good condition although there has been flow through the structure and racking is missing from the tip of the left wing. This damage probably occurred in 2011, when large anabranches of the NFTR were interacting with both wings of the structure. Scour continued at the right wing in 2012 and 2013 due to the presence of a secondary anabranch. The vegetated area of the island is small due to lateral erosion by this and other relatively small but aggressive anabranches of the NFTR, which have re-worked previously deposited sediments and removed emergent vegetation. Plants are mostly riparian types, with few trees. The right wing is currently being actively undercut by confluence scour due to the meeting of flow in two smaller anabranches of the NFTR, one of which is deflected by the center of the structure to flow along the right wing, while the other approaches that wing head on. In this regard, **C**raig is currently functioning adequately by withstanding the fluvial scour associated with the secondary anabranches and protecting the island and its vegetation. It might not function adequately if again attacked by the mainstream of the NFTR in future, though. Hence, monitoring must continue to allow time for repairs should the NFTR move back to the vicinity of this structure.

Figure 5.6 Condition Assessment for Structure C - **C**raig.

Structure	Condition	Functionality	Maintenance Requirement
Dwayne	Unsatisfactory	Partial	Urgent Repair

Dwayne is in good condition structurally considering that channels were scoured on both flanks of **D**wayne in 2011 by anabranches of the mainstream NFTR (see Figure 3.33). However, the right wing and the right third of the center section lost all their racking such was the ferocity of the fluvial attack in 2011. The island has a well vegetated, diamond shaped center, although the marker post indicates that there has been no net accretion of sediment behind the structure since its construction. There was accretion around **D**wayne in 201 and it is not currently experiencing intensive flow attack from the NFTR, but it would be highly vulnerable should the river sweep back to the south or avulse onto a new course that renewed scour around the structure. In this eventuality, **D**wayne would be partially functional at best, allowing erosion and reworking of its island and functioning only about as well the two Type-B structures immediately upstream (**K**im and **J**im), are functioning at present.

Figure 5.7 Condition Assessment for Structure D - **D**wayne.

Structure	Condition	Functionality	Maintenance Requirement
Eager	Good	As Intended	Monitor & Report

Eagar is in good to excellent condition and is functioning as intended. In 2011 and 2012, **E**agar deflected scouring anabranches of the NFTR to either side of the structure, but currently, **E**agar is deflecting the main channel of the NFTR across the upstream face of the structure, to the right. This is protecting the island although it is directing the flow on to the left wing of the next structure to the right (Of**F**ice) and that oblique attack has caused extensive damage to Of**F**ice. Structurally, **E**agar is 'as built' and its racking is still present, although it is dry, shrunken and therefore not as effective in deflecting flow and protecting the island downstream of the structure as it would have been when first installed. The island is extensive and clearly defined – in this respect, **E**agar's island currently sets the performance standard for an island-forming structure. Vegetation in it indicates that part of the vegetated island that had developed in the past has been re-worked, though it is unclear when. The re-worked area is now again re-vegetating, demonstrating the resilience of the island when the racking stays in place and the structure performs as intended.

Figure 5.8 Condition Assessment for Structure E - **E**agar.

Structure	Condition	Functionality	Maintenance Requirement
Of**F**ice	Unacceptable	Dysfunctional	Critical -Repair

The left wing of Of**F**ice was first attacked by an anabranch of the NFTR in 2012, but it deflected flow successfully to the left (see Figure 3.33). It was still fully functional when inspected on June 5th 2013, but by late-July strong fluvial attack by the main channel of the NFTR had seriously damaged it by scouring the bed, berm and removing racking throughout the left wing and over half the centre of the structure. This occurred due to high, snowmelt flow that was deflected by **E**agar to approach Of**F**ice at an oblique angle. Flow attack then shifted laterally in a growing curve downstream of Of**F**ice to re-erode sediment that had been deposited behind the structure and cut an embayment 50 m deep into the proto-floodplain on the right (north) margin of the sediment plain, where there was on June 5th a young but dense stand of alders. Hence, despite limiting the NFTR from migrating even further into the proto-floodplain and shielding the next structure in the second row (**G**urney) in 2013, Of**F**ice must now be classified as dysfunctional. Currently, only the right 1/3rd of the center and the right wing of Of**F**ice still have any of their original racking and berm intact, and both will be lost as scour within the structure continues. Consequently, loss of sediment and vegetation behind the structure are likely to continue unless the Of**F**ice is repaired and strengthened before next year's rainstorm and snowmelt floods; making repair time critical.

Figure 5.9 Condition Assessment for Structure F - Of**F**ice.

Structure	Condition	Functionality	Maintenance Requirement
Gurney	Excellent	As Built	Monitor & Report

Gurney is almost (perhaps completely) undamaged by the NFTR and is essentially 'As Built' except that its racking has dried out and shrunk in height and volume. This is the case because the NFTR has not flowed through the area around the structure since 2009 and the structure and its zone of influence is currently contained entirely within the right margin proto-floodplain in the sediment plain. Alders dominate the dense vegetation not only behind but all around the structure. There is a small, abandoned channel between **G**urney and Of**F**ice, which did generate some scour close to the left wing in 2011. To the right, a corridor of sparse vegetation exists, up to a dense alder hedge that separates that corridor from the next back channel – which does have water in it. This pattern of channels separated by dense hedges of alders continues to the wall-base channel between the edge of the sediment plain and the north valley side.

Figure 5.10 Condition Assessment for Structure G - **G**urney.

Structure	Condition	Functionality	Maintenance Requirement
Jo**H**n	Unsatisfactory	Partial	Urgent - Repair

Jo**H**n was subjected to heavy attack by the NFTR mainstream in both 2011 and 2012, but has come through relatively well. Racking is damaged on the left wing, missing almost entirely in the centre but is more or less intact on the right wing. The island behind the structure has been reworked by flow passing through the structure at some time and vegetation (riparian species) is sparse and young as a result. Willows are doing OK in the right wing, which has been protected by the intact racking. Structurally, John has not been damaged even by attack by the full force of the NFTR for 2 years, and the structure should be left alone for a while now as the river is migrating to the north and away from it. However, attack could be renewed at any time should the mainstream or a large anabranch avulse back to the south. In that eventuality, Jo**H**n's lack of racking would expose the island behind the structure to erosion and reworking, effectively rendering it at best partially functional. To preclude this possibility, repair of the structure is required urgently.

Figure 5.11 Condition Assessment for Structure H - Jo**H**n.

Structure	Condition	Functionality	Maintenance Requirement
sl	Acceptable	Adequate	Maintain & Report

S**I** was not attacked as heavily Jo**H**n in 2011, though it did interact with anabranches of the NFTR mainstream in 2012. It is structurally sound and it has most of its racking in place as a result. That said, it appears that flow has come through the center and left wing, probably between 2011 and 2012, as the NFTR migrated northwards. The berm in these parts of the structure has been eroded and there are signs of reworking (i.e. erosion and re-deposition) and removal and re-growth of vegetation. The island is vegetated by riparian species but its area is truncated on the left side by a currently abandoned sub-channel of the NFTR that once flowed across the back of S**I** from left to right – similar to the channel currently attacking Wa**L**sh. S**I**'s condition assessment demonstrates that while flow through or across the back of a structure re-erodes accumulated sediment and vegetation from the island, the island recovers subsequently when the channel passing through the structure migrates away or is abandoned. Nevertheless, if attacked again by a large sub-channel of the NFTR, S**I** would provide limited protection to its island and would, therefore, function partially at best. As such flow attack could be renewed at any time, urgent repairs to the racking and berm are necessary.

Figure 5.12 Condition Assessment for Structure I - S**I**.

Structure	Condition	Functionality	Maintenance Requirement
Jim	Unacceptable	Dysfunctional	Critical -Repair

Jim was attacked by a substantial anabranch of the NFTR in 2011, mainly on its left wing, and by a branch of the mainstream in 2012. The structure is unusual in that the racking is in fairly good condition, but is currently ineffective in deflecting all of the flow in the approaching main channel of the NFTR as it strikes the centre of the structure. Most of the flow is successfully deflected to the right, but a portion goes straight on under and through the centre of Jim. This is because deep scour and high approach velocities in the NFTR mainstream have scour below the racking and water is passing underneath it. This flow has washed out sediment, the berm and vegetation within and behind the centre part of the structure, exposing the central part of the island to serious scouring. Allowing some of the mainstream flow to pass through the structure may, however, have been of benefit to **K**im, **E**agar and Of**F**ice (which are in turn attacked by flow that is deflected to the right by **J**im), because it has reduced the discharge and ferocity of attack on the left wings of each of these structures. That said, repair is necessary to make Jim functional again and this is critical as, of all the structures in the upstream row, **J**im is the one that currently takes the full force of the NFTR mainstream approaching from upstream.

Figure 5.13 Condition Assessment for Structure J – **J**im.

Structure	Condition	Functionality	Maintenance Requirement
Kim	Unsatisfactory	Partial	Urgent Repair

Kim's left wing was persistently attacked by a large anabranch of the NFTR in 2011, which scoured a deep channel close to and partially within the left wing of the structure. That channel migrated into the left wing in 2012. In 2013 the mainstream NFTR approached the study area along an axis between **J**im and **K**im, with most of the flow being deflected laterally to the right by **J**im, to attack **K**im's left wing at an oblique angle. A second, smaller anabranch attacked the right wing at the same time. Despite experiencing persistent fluvial attack, **K**im is still functioning at perhaps 60% of full efficiency, but it has lost all racking from the left wing, except for a single, large log placed between the two rows of piles, which is preventing much worse scour by the mainstream of the NFTR in that part of the structure and reducing re-erosion in the island behind the right wing and centre. Re-erosion of the island has also been reduced by **K**im's unusual construction, which included additional logs placed at the level of the sediment plain within and behind the structure and no trench being excavated in front of the structure. The presence of these logs does seem to have somewhat inhibited re-working of the island, which has preserved more of the vegetation than might have otherwise been the case. The right wing is still deflecting the second, smaller anabranch of the NFTR effectively. **K**im's current condition requires urgent repair and replacement of the lost racking and rebuilding of the damaged berm in order to restore the structure to full functionality. This is necessary as **K**im, like **J**im, is a frontline structure that experiences the full force of the approaching NFTR mainstream and its anabranches.

Figure 5.14 Condition Assessment for Structure K - **K**im.

Structure	Condition	Functionality	Maintenance Requirement
Wa**L**sh	Acceptable	Adequate	Maintain & Report

Wa**L**sh performed really well between 2010 and 2012, when it was subjected to serious frontal attack by secondary, but aggressive anabranches of the NFTR, building a well-defined and vegetated island in the process (see Figure 3.34). However, in 2013 one of the anabranches of the mainstream NFTR deflected to the right by **J**im has been flowing laterally across the back of Wa**L**sh and this has completely removed the sediment and vegetation that had accumulated and grown in its island, re-eroding all the way back to the rear edge of the berm. The vegetated island that had developed between 2010 and 2012 has been almost entirely lost as a result. Also, Wa**L**sh is currently providing little or no protection to the structures behind it in the second row (especially Of**F**ice) from flow in the NFTR mainstream as its channels cross the sediment plain from left to right at a highly oblique angle between the rows of structures,. Despite persistent attack from the front and the side, Wa**L**sh is structurally sound, but its racking has deteriorated and is in poor condition (dry, brittle, buoyant). Also, its berm has been damaged on both ends, though the central section is intact and is becoming sparsely vegetated with alders. The condition of Wa**L**sh demonstrates how vulnerable the vegetated islands behind the structures are to re-erosion by anabranches that flow across the back of the structure. This is because the wings of the structures do not angle back very steeply and so protect from lateral attack only a shallow pocket immediately behind the central part of the structure. Given the propensity of anabranches of the NFTR to flow at an oblique angle across the sediment plain, this suggests that lack of protection from scour by oblique flow may lead to relatively frequent re-working of island sediments that may limit the lifespan of vegetation growing on the islands.

Figure 5.15 Condition Assessment for Structure L - Wa**L**sh.

Structure	Condition	Functionality	Maintenance Requirement
Mike	Good	As Intended	Monitor & Report

Mike has been attacked by a secondary anabranch of the NFTR/Hoffstadt Creek almost continuously since 2010. While this anabranch has scoured a deep channel in front of and to the right of the structure, **M**ike remains structurally sound and continues to be effective in protecting from lateral erosion the proto-floodplain on the right margin of the sediment plain. Also, **M**ike provides important protection to Of**F**ice (which is in the second row, behind **M**ike and to its left). In fact, together, **M**ike and Of**F**ice are currently the two most important structures in providing effective scour control to the sediment body and young vegetation at the right margin of the sediment plain, plus they are protecting **G**urney and Ge**N**e from attack by the NFTR. **M**ike is in good condition, with 90% of its racking still in place. Its island is effectively part of the proto floodplain at the right edge of the sediment plain and extends downstream as far as Of**F**ice which, as noted above, has benefitted from the protection from attack by the smaller anabranch of the NFTR. In fact, the NFTR may well have moved laterally through Of**F**ice entirely by now (rather than just 2/3^{rds} of the way through from left to right), if **M**ike had not, since 2010, functioned as intended. Given the importance of **M**ike, monitoring is essential to identify when the need for maintenance will become urgent, so that this can be performed in a timely manner and before **M**ike loses functionality or becomes dysfunctional.

Figure 5.16 Condition Assessment for Structure M - **M**ike.

Structure	Condition	Functionality	Maintenance Requirement
Ge**N**e	Excellent	As Built	Monitor & Report

Ge**N**e is in ‘As Built’ condition. It has no flow damage and may not have been affected by any NFTR anabranches since its construction, although streams of water that have either come from Hoffstadt Creek or exfiltrated out of the sediment plain have scoured small channels to either side of the structure. Ge**N**e’s ‘island’ is better described as a ‘zone of influence’ because it is not an island as such. In fact, the zone influenced by Ge**N**e is fully contained within the proto-floodplain developing at the right margin of the sediment plain. The proto-floodplain features dense hedges and patches of vegetation (mainly alders), especially around the right half of the structure. As it is doubtful that there has been substantial NFTR flow over the surface of the proto-floodplain since 2010, probably this pattern of vegetation is related to flow in Hoffstadt Creek or, more likely, that exfiltrating from the surface of the sediment plain, rather than the impacts of the structure *per se*. The berm is located behind the second row of posts rather than being between the first and second rows, as is the case for the other Type-A structures. Ge**N**e should function 'as built' if attacked by the NFTR, although the height and volume of racking have been reduced by drying and weathering which have increased the buoyancy of the wood and made it brittle. It would be unfortunate if Ge**N**e were to be attacked by anabranches of the NFTR, and this need not happen provided that **M**ike and Of**F**ice perform effectively in protecting Ge**N**e and **G**urney from attack by the main river. Guaranteeing that future protection will, however, require critical repairs to Of**F**ice and close monitoring of **M**ike.

Figure 5.17 Condition Assessment for Structure N - Ge**Ne**.

Appendix E: Sedimentation induced by raising the spillway in 2012

July 2013: Sedimentation upstream of the SRS in response to the 2012 spillway raise (photograph taken by lead author)


September 2013: Note vegetation on newly deposited surfaces (photograph taken by lead author)

Appendix F: Selected photographs of Cross-Valley Structure, False Valley Wall and Diversion Berm in 2013

Cross Valley Structure. Note how large body of sand stored upstream of the **CVS** is excluding the NFTR and diverting around the **False-Valley Wall.**

Cross-Valley Structure. Note extensive vegetation (including shrubs, trees and wetland species) now colonising the cells within the structure.

False-Valley Wall. Note generally good condition and continued effectiveness of geotube, but leaning of piles, sinking of tube and loss of protective fabric covering the geotextile at upstream, end due to local scour.

Diversion Berm. view along berm from southern end. Note elevation difference between sediment plain upstream and downstream of berm and low elevation of berm crest relative to sediment plain upstream.

Diversion Berm. View upstream. Note extensive sand deposit upstream of berm that excludes NFTR, good condition of berm structure and extensive, vegetation downstream, with well developed channel network carrying exfiltrating, clear water flow that has probably seeped beneath the Diversion Berm.